PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME LXXV

1935

CONTENTS

LIST OF ILLUSTRATIONS

Stated Meeting, January 4, 1935

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

The President read the following radio message received
from Little America: [Byrd Antarctic Expedition II].

"I am pleased to report that the Seismic Soundings
are coming along nicely and that we have to date about
three hundred fifty soundings distributed over eighty
stations. The method is proving very satisfactory and
giving the ice thickness whether it is floating or grounded,
if floating the thickness of the water layer as well as
something of the stratification of the underlying rock.
Regards
(signed) THOMAS C. POULTER."

The decease of the following members was announced:
Sir E. A. Wallis Budge, Kt., M.A., Litt.D., F.S.A., at
London, November 23, 1934, æt. 77
Palmer C. Ricketts, C.E., E.D., LL.D., at New York,
December 10, 1934, æt. 78
Theobald Smith, Ph.B., M.D., A.M., LL.D., Sc.D., at
Princeton, December 10, 1934, æt. 75
Roland B. Dixon, Ph.D., at the town of Harvard, De-
cember 20, 1934, æt. 59
G. Carl Huber, M.D., Sc.D., at Ann Arbor, December
26, 1934, æt. 69

Edward L. Bowles and Henry G. Houghton, Jr., Massa-
chusetts Institute of Technology, presented a Report of

Progress on "Fog Dissipation by Hygroscopic Material," a project sponsored by the Society. The paper was discussed by Mr. H. S. Morris and Colonel Wetherill.

The following paper was read by title:
"Siwalik Mammals in the American Museum of Natural History," Edwin H. Colbert, American Museum of Natural History. (Introduced by Professor Scott.)

Stated Meeting, February 1, 1935
EDWIN G. CONKLIN, Ph.D., Sc.D., LL.D.,
Vice-president, in the Chair

Herbert S. Jennings, Ph.D., Sc.D., LL.D., Henry Walters Professor of Zoology and Director of the Zoological Laboratories, The Johns Hopkins University, read a paper on "What is the Rôle of Mutations in Evolution?" The paper was discussed by Drs. McClung and Conklin.

The decease of the following members was announced:
Alba B. Johnson, LL.D., at Rosemont, Pa., January 8, 1935, æt. 76.
Lyman B. Hall, Ph.D., at Haverford, Pa., January 20, 1935 æt. 83.

The following papers were read by title:
"Manus Religion—An Ethnological Study of the Manus Natives of the Admiralty Islands," R. F. Fortune. (Introduced by Dr. Donaldson.)
"Description of Some Notoungulates from the Casamayor (Notostylops) Beds of Patagonia," Elmer S. Riggs and Bryan Patterson, Field Museum of Natural History. (Introduced by Professor Scott.)
The members of the Society will learn with regret that Dr. Arthur W. Goodspeed has resigned as Secretary of the Society.

As the President stated at the last meeting Dr. Goodspeed has served as Secretary with amazing faithfulness for nearly thirty-four years.

The following resolution was adopted:

That the members of the Society wish to express their deep
regret at Dr. Goodspeed's resignation and also their
sincere appreciation of his long years of faithful service.
It is hoped that his interest in the Society will not
diminish and that he will long continue his work as
Editor of the Society's publications.

Stated Meeting, March 1, 1935

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

Horace Howard F. Jayne, recently elected member, sub-
scribed the Laws and was admitted into the Society.

The decease of the following members was announced:

Herman V. Ames, A.M., Ph.D., Litt.D., LL.D., at
Philadelphia, February 6, 1935, æt. 70.

C. David White, B.S., D.Sc., at Washington, February
7, 1935, æt. 72.

Lyon G. Tyler, A.M., LL.D., at Charles City County,
Virginia, February 12, 1935, æt. 81.

Elisha Kent Kane, C.E., at Kane, Pa., February 18,
1935, æt. 78.

Samuel Alfred Mitchell, Ph.D., LL.D., Director, Leander
McCormick Observatory, University of Virginia, read a
paper on "Solar Eclipse Problems," which was illustrated with
lantern slides.

Annual General Meeting, April 18, 19, 20, 1935
Thursday Morning, April 18th
Executive Session, 9:30 o'clock

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

The President presented a detailed account of the activities
and finances of the Society.

The following resolution was unanimously adopted:

Resolved: That the Society assembled in annual meeting approve and adopt the recommendation of the Council and authorize the President under advice of counsel to abrogate the contract with the City of Philadelphia and abandon all plans to build on the parkway and be it further *Resolved* that the President communicate with all contributors to the building fund and request said contributors to permit the use of said building fund for building or for the general purposes of the Society, authority being hereby given to the President, with the approval of the Council, to return to any contributor the whole or any part of his contribution should the President and Council deem such action advisable.

The President announced that Mrs. Lewis had made a gift of $10,000 to the Society in memory of her husband, John F. Lewis; the income to be used each year as an award to the American citizen who shall announce at any general or special meeting of the Society, and publish among its papers, some truth which the Council of the Society shall deem worthy of the award.

The following resolutions were unanimously adopted:

Resolved: That the question of the acceptance and the terms of acceptance of the Walter Wood bequest be referred to the Finance Committee which Committee shall have full power and authority to act for the Society, and to pay out of the funds of the Society such sums as may be required to release the real estate bequeathed from the lien of decedent's debts.

Resolved, That it is the sense of this meeting that the Society formally accept the Constitution of 1873 and the Non-profit Corporation Law of 1933 and that the Charter of the Society be amended to enable the Society to accomplish the purposes set forth in the preamble and

Further Resolved, That the Officers of the Society be empowered and directed to take all necessary action to accomplish this purpose including the calling of such

special meeting or meetings of the Society as may be necessary.

   Resolved, That an award of $1500 from the Henry M. Phillips Prize Essay Fund be made to Lon Fuller for his work on the Science and Philosophy of Jurisprudence, culminated in his last paper, "American Legal Realism," and that the award be made at a Special Meeting of the Society to be held on October 4, 1935.

The decease of the following members was announced:

   William Duane, Ph.D., Sc.D., at Devon, March 7, 1935, æt. 63.

   Michael I. Pupin, Ph.D., Sc.D., LL.D., at New York, March 12, 1935, æt. 76.

   William J. Sinclair, Ph.D., at Princeton, March 26, 1935, æt. 58.

   Adolph S. Ochs, LL.D., Litt.D., at Chattanooga, Tenn., April 8, 1935, æt. 77.

Dr. Conklin, Chairman of the Committee on Grants, presented his report.

Morning Session, 10:30 o'clock

EDWIN G. CONKLIN, Ph.D., Sc.D., LL.D.,
Vice-president, in the Chair

The following reports of Progress on Projects sponsored by the Society were presented:

   "Factors Affecting Mutation Rate in Seeds of Datura." J. L. Cartledge, A. F. Blakeslee, Department of Genetics, Carnegie Institution of Washington, and L. V. Barton, Boyce Thompson Institute for Plant Research.

   "Further Biological Studies on the Thymus Gland." Leonard G. Rowntree, Director, Philadelphia Institute for Medical Research. Discussed by Dr. Donaldson.

   "Species Relationships in Onagra." Ralph E. Cleland, Goucher College and P. A. Munz, Pomona College.

"The Furness Variorum Shakespeare." M. A. Shaaber,
University of Pennsylvania.

"Research Work on Element 91." A. V. Grosse, University of Chicago.

"The Nature of the Primary Cosmic Radiation." W.
F. G. Swann, Director, Bartol Research Foundation
of the Franklin Institute.

"An Automatic Respiration Calorimeter for Study of
the Continuous Heat Production of Small Animals."
John R. Murlin and William M. Barrows, Jr., Department of Vital Economics, University of Rochester.

A written report from Edward L. Bowles and H. C.
Houghton Jr. on their Fog Dissipation project was submitted.
Dr. Conklin gave a brief outline of the results attained.

A Report of Progress on the White River Fauna by
William B. Scott and Glenn L. Jepsen was presented.

Afternoon Session, 2 o'clock

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

Edward L. Thorndike, recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Slavonic Loan Material in Hungarian," John Dyneley
Prince, Professor of Slavonic Languages, Columbia
University. (Read by title.)

"The Alps in History," Walter Woodburn Hyde,
Professor of Greek and Ancient History, University
of Pennsylvania. (Introduced by Dr. Montgomery.)

"Dictatorships and Democracy," Robert Brooks, Professor of Political Science, Swarthmore College.
(Introduced by Dr. Lingelbach.)

"Mr. Jefferson, The William Byrd Manuscripts, and
The American Philosophical Society," St. George
L. Sioussat, Professor of American History, University
of Pennsylvania.

"Some Fragments of the Oldest Beatty Papyrus in the Michigan Collection," Henry A. Sanders, Professor of Latin, University of Michigan.

"Publication as a Scientific Problem," J. R. Schramm, Editor-in-Chief, Biological Abstracts, University of Pennsylvania.

"Proposed Reforms of the Gregorian Calendar," Arthur E. Kennelly, Professor Emeritus, Harvard University.

"The Paradox of Science," E. L. Thorndike, Professor of Psychology, Teachers College, Columbia University.

"The Revolt Against Taste," Harrison S. Morris, Philadelphia.

Thursday evening, 8 o'clock

THE R. A. F. PENROSE, JR., MEMORIAL LECTURE

W. F. G. Swann, Director, Bartol Research Foundation of the Franklin Institute, spoke on "Is the Universe Running Down?"

Friday Morning, April 19th

Executive Session, 9:30 o'clock

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

Jesse S. Reeves, recently elected member, subscribed the Laws and was admitted into the Society.

The proceedings of the Council were submitted.

The Society proceeded to an election. The tellers subsequently reported that the following officers and members had been duly elected:

President

Roland S. Morris

Vice-presidents

Edwin G. Conklin

Robert A. Millikan

Henry H. Donaldson

Secretaries
John A. Miller
William E. Lingelbach

Curator
Albert P. Brubaker

Councillors
(To serve for three years)
Frank Aydelotte
Isaiah Bowman
Gustavus W. Cook
Harlow Shapley

(To fill unexpired term)
(To serve for two years)
William Trelease

Members
Residents of the United States
Roger Adams, Urbana, Ill.
Leo H. Baekeland, New York, N. Y.
Franz Boas, Grantwood, N. J.
L. J. Briggs, Washington, D. C.
William L. Bryant, Providence, R. I.
Rhys Carpenter, Philadelphia, Pa.
George Ellett Coghill, Philadelphia, Pa.
James Bryant Conant, Cambridge, Mass.
H. N. Davis, Hoboken, N. J.
Frederic Adrian Delano, Washington, D. C.
Harold Willis Dodds, Princeton, N. J.
Franklin Edgerton, New Haven, Conn.
Frank Albert Fetter, Urbana, Ill.
Dixon Ryan Fox, Schenectady, N. Y.
Yandell Henderson, New Haven, Conn.
Karl Landsteiner, New York, N. Y.
Charles Edward Merriam, Chicago, Ill.

George Richards Minot, Boston, Mass.
Eugene Gladstone O'Neill, Sea Island, Ga.
Frederick Leslie Ransome, Pasadena, Calif.
Alfred Newton Richards, Philadelphia, Pa.
F. K. Richtmyer, Ithaca, N. Y.
Harold Clayton Urey, New York, N. Y.
Hermann Weyl, Princeton, N. J.
William Hammond Wright, Mt. Hamilton, Calif.

Foreign Resident

Arthur Berriedale Keith, Edinburgh, Scotland

Dr. Sioussat gave a résumé of the Library Committee's
Report and of its future plans. (Which is on file.)

The purchase of the Bache Collection was considered.
After full discussion the meeting adopted the following reso-
lution:

> *Resolved,* That the purchase of the Bache Collection
> be left to the full discretion of the President and Council.

Dr. Donaldson presented a short report on the activities
of the Committee on Publications.

Dr. E. V. Huntington moved that a Committee be ap-
pointed to study and report upon the question as to whether
or not the Society should endorse either of the two principal
proposals for calendar reform mentioned in the League of
Nations Report of 1931. A Committee of three was so ap-
pointed.

Morning Session, 10:30 o'clock

ROBERT A. MILLIKAN, Ph.D., Sc.D., LL.D.,
Vice-president, in the Chair

The following papers were presented:
  "Electrical Distributions on Circular Cylinders," E. P.
    Adams, Professor of Physics, Princeton University.
  "Methods for the Separation of Isotopes," Harold C.
    Urey, Professor of Chemistry, Columbia University.
    (Introduced by Dr. Taylor.)

"The Nervous Control of the Heart," Detlev W. Bronk,
Professor of Biophysics and Director, Eldridge Reeves
Johnson Foundation for Medical Physics, University
of Pennsylvania.

"Chromosome Linkage and Gene Linkage in Œnothera
Lamarckiana," George H. Shull, Professor of Botany
and Genetics, Princeton University and John Theron
Illick, University of Nanking, China.

"Relationships between Œnothera Blandina and Œno-
thera Franciscana," Bradley M. Davis, Professor of
Botany, University of Michigan.

"The Distribution of Living Plants in Relation to
Geological History," M. L. Fernald, Fisher Pro-
fessor of Natural History, Harvard University. (In-
troduced by Dr. True.)   (Read by title.)

"The Antarctic Flora of Pre-glacial Times as Explained
by the Present Distribution of Plants in the Southern
Hemisphere," Carl Skottsberg, Visiting Professor,
Botanical Department, Yale University. (Intro-
duced by Dr. True.)

"The Pedicellate Peppers of South America," William
Trelease, Professor Emeritus, University of Illinois.
(Read by title.)

Afternoon Sesson, 2 o'clock
EDWIN G. CONKLIN, Ph.D., Sc.D., LL.D., Vice-president, in
the Chair

The following papers were presented:

"Some Reflections Regarding Human Heredity," Aleš
Hrdlička, Curator, Division of Physical Anthropology,
U. S. National Museum, Smithsonian Institution.

"Development and Correlation of Research in Physical
Anthropology at Harvard University," Earnest A.
Hooton, Professor of Anthropology, Harvard Univer-
sity.

"Cryptaspis and other Lower Devonian Fossil Fishes
from Beartooth Butte, Wyoming," William L. Bryant,

Director, Park Museum.   (Introduced by Dr. W. B.
Scott.)   (Read by title.)

"Carnivora and Insectivora on the White River Beds,"
William B. Scott, Professor Emeritus and Glenn L.
Jepsen, Princeton University.

"The Disappearance of Primary Caudal Bands in the
Tail of Fundulus and Its Relation to the Neuro-
humoral Hypothesis," G. H. Parker, Director, Zoo-
logical Laboratories and Professor of Zoology, Har-
vard University.

"A Provisional Hypothesis of Child Development,"
Charles B. Davenport, Department of Genetics, Car-
negie Institution of Washington, Cold Spring Harbor.

"Old Age Furnishes a Concept of Basal Metabolism,"
Francis G. Benedict, Director, Nutrition Laboratory,
Carnegie Institution of Washington, Boston.

"The Reproductive Capacity of Fungi with Example
from a Giant Puff Ball," Albert F. Blakeslee, Acting
Director, Department of Genetics, Carnegie Institu-
tion of Washington, Cold Spring Harbor.

"Aspects and Implications of the Hormonal Control of
the Maternal Instinct," Oscar Riddle, Research Staff,
Station for Experimental Evolution, Carnegie Insti-
tution of Washington, Cold Spring Harbor.

"The Behavior of the Neuromotor System of the Ciliates
at Binary Fission," Charles A. Kofoid, Professor of
Zoology, University of California.   (Read by title.)

Saturday Morning, April 20th

Morning Session, 10 o'clock

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

Arthur J. Dempster, W. D. Harkins, Norman L. Bowen,
and Harold C. Urey, recently elected members, subscribed
the Laws and were admitted into the Society.

The following papers were presented:

"Cosmic Rays." Robert A. Millikan, Director, Norman
Bridge Laboratory of Physics, and Chairman, Execu-
tive Council, California Institute of Technology.

"The Composition of Cosmic Rays," Arthur H. Comp-
ton, Professor of Physics, University of Chicago.

"The Atmospheres of the Planets," Vesto M. Slipher,
Director, Lowell Observatory.

"Problems Presented by a Study of Fireballs Recently
Observed in America," Charles P. Olivier, Professor
of Astronomy and Director of the Flower Observa-
tory, University of Pennsylvania.

"New Methods in Mass Spectroscopy," A. J. Demp-
ster, Professor of Physics, University of Chicago.

Afternoon Session, 2:30 o'clock

The meeting was held in the Franklin Institute.

Dr. Howard McClenahan, Director, gave a brief sketch of
the history and activities of the Franklin Institute.

Saturday Evening, 7:30 o'clock

The annual dinner was held at the Bellevue Stratford
Hotel, President Morris presiding.

The speakers at the dinner were Harlow Shapley, Edwin
G. Conklin, and Henry H. Donaldson.

Special Meeting, October 4, 1935

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

Frank P. Graves, recently elected member, subscribed the
Laws and was admitted into the Society.

The President called for a report of the Sub-committee of
the Council on the Revision of the By-laws appointed in
accordance with the action of the Council at its meeting in
January 1935.

Professor Conklin reported for the Committee, submitting
the proposed revision of the By-laws which had been printed
and duly distributed to the membership for consideration.

Dr. Sioussat moved that the report on the amendment to the Laws be accepted as submitted subject to the various amendments and suggestions submitted during the meeting. The Laws were on motion accepted under these conditions and referred back to Council.

Conformable to the Charter and Laws of the Society and the Nonprofit Corporation Law, there were submitted in writing the following proposed amendments to the Charter and form of Acceptance of the Constitution of the Commonwealth of Pennsylvania and the Nonprofit Corporation Law:

ARTICLES OF AMENDMENT

Article I

Notwithstanding the Proviso at the end of the first paragraph following the preamble of this Charter, or any other proviso thereof, the Society shall have the capacity and authority without limitation by this Charter to purchase, take, receive, lease as lessee, take by gift, devise or bequest, or otherwise acquire, and to own, hold, use, and otherwise deal with any and all real or personal property, or any interest therein, wherever situated.

Article II

And provisions of this Charter which are purely administrative in their nature, including those concerning the officers, the members of the council, and the date and time of meetings, may be altered by a law, regulation or ordinance of the Society duly adopted and not repugnant or contrary to the laws of this Commonwealth.

The foregoing proposed amendments and certificate of acceptance were submitted pursuant to a resolution adopted by the Society at its Executive Session held on Thursday, April 18, 1935, authorizing the officers of the Society to take all necessary action to amend the Charter and to accept the Constitution.

The following resolutions recommended by Council were adopted by the Society:

Resolved, That the American Philosophical Society, having considered the two principal proposals for calendar reform mentioned in the League of Nations Report of 1931, hereby expresses its preference for the 12-month plan known as the World Calendar; and

Resolved, That the Society would welcome the adoption of this 12-month plan, provided a substantially unanimous agreement among the civilized peoples of the world is secured in favor of the change.

Copies of the above resolutions were ordered sent to the League of Nations, the State Department, the World Calendar Association, and the International Fixed Calendar League.

Evening Session, 8:15 o'clock
ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D.,
President, in the Chair

The President presented the Henry M. Phillips Prize Award with an engrossed congratulatory statement to Lon L. Fuller of Duke University for his work on the Science and Philosophy of Jurisprudence culminated in his article "American Legal Realism."

Dean Goodrich of the University of Pennsylvania introduced Dr. Fuller. Dr. Fuller made a short response to this introduction.

Thomas C. Poulter, Second in Command of the Byrd Antarctic Expedition II, gave an interesting account of the Expedition which was illustrated by motion pictures. This was the first field report on the expedition made by Dr. Poulter.

Stated Meeting, November 1, 1935
HENRY H. DONALDSON, Ph.D., Sc.D., Vice-president, in the Chair

The decease of the following members was announced:

Charles E. St. John, B.S., A.M., Ph.D., Sc.D., at Pasadena, Calif., April 26, 1935, æt. 78.

Edwin Brant Frost, A.M., Sc.D., at Williams Bay, Wis., May 12, 1935, æt. 69.

Herman Collitz, A.M., Ph.D., L.H.D., at Baltimore,
Md., May 13, 1935, æt. 80.

Hugo de Vries, D.L., D.Sc., at Lunteren, Holland, May
21, 1935, æt. 87.

Edward S. Dana, Ph.D., at New Haven, Conn., June 16,
1935, æt. 85.

Thomas McCrae, A.B., M.D., at Philadelphia, July 1,
1935, æt. 65.

Harold Goodwin, A.B., A.M., LL.B., at Philadelphia,
August 16, 1935, æt. 85.

Charles Elwood Mendenhall, B.S., Ph.D., at Madison,
Wis., August 18, 1935, æt. 63.

Barton Cooke Hirst, A.B., M.D., LL.D., Sc.D., at
Philadelphia, September 2, 1935, æt. 74.

Alexander C. Abbott, M.D., Sc.D., Dr. P.H., at Cape
Cod, September 11, 1935, æt. 75.

William Wallace Atterbury, Ph.B., M.A., LL.D., at
Philadelphia, September 20, 1935, æt. 69.

Carl Barus, Ph.D., LL.D., at Providence, R. I., September 20, 1935, æt. 79.

Adolph Washington Greely, Major General, U.S.A., at
Washington, D.C., October 21, 1935, æt. 91.

Roderick Macdonald, Director of the Zoological Garden of
Philadelphia, presented a paper on The Symmetry in Nature,
based upon the Study of the Echinoderms, which was illustrated by lantern slides. The paper was discussed by a guest.

A miniature of Benjamin Franklin was presented to the
Society by Mrs. Joshua L. Barton and on motion thanks were
ordered.

A portrait of Andrew Carnegie, in commemoration of the
one hundredth anniversary of his birth, was presented to the
Society by the Carnegie Corporation of New York, and was
accepted with thanks.

The following resolution, recommended by the Committee
on Library, was adopted by the Society:

Resolved, That the American Philosophical Society's
Committee on Library hereby places on record its deep

appreciation and gratitude for the very generous gift of one hundred and seventy-eight volumes presented by Mrs. Gest in memory of her husband, Judge John Marshall Gest, an honored member of the Society from 1921 until his death, November 30, 1934.

Stated Meeting, December 6, 1935

ROLAND S. MORRIS, LL.B., LL.D., D.C.L., L.H.D., President, in the Chair

The decease of the following members was announced:
Henry Fairfield Osborn, Sc.D., Ph.D.. LL.D., at Garrison-on-Hudson, N. Y., on November 6, 1935, æt. 78.
James H. Breasted, Ph.D., LL.D., at New York, on December 2, 1935, æt. 70.

The dates of the Annual General Meeting. April 23, 24, 25, 1936, were formally approved.

The Council's recommendation that the President be authorized and directed to renew the offer for the Bache collection was on motion unanimously carried.

On motion the proposals to accept the Constitution and the Nonprofit Corporation Law, and to amend the Charter of the Society were submitted to the vote of the members. Both proposals had previously been submitted in writing at the meeting of the members held on Friday, October 4, 1935. Notice that action would be taken on the proposals at this meeting was given to each member under date of November 9, 1935. Similar notice was published in the Legal Intelligencer on November 20, 1935 and in the Philadelphia Inquirer on November 20, 1935, conformable to the requirements of the Charter and Laws of the Society, and the Nonprofit Corporation Law. Both proposals were adopted by a unanimous vote, there being twenty-one members present, not less than four of whom are members of Council.

Pursuant thereto the following resolutions were adopted, to be incorporated in these minutes:

WHEREAS conformable to the Charter and Laws of The American Philosophical Society proposed amendments to the Charter of the Society were heretofore submitted in writing to the members:

Now therefore be it resolved that the said amendments to the Charter of the Society as heretofore submitted be and are hereby approved and the proper officers of the Society are instructed to proceed to make them effective by petitioning the Courts of Common Pleas and to take all other actions necessary to that end under the Nonprofit Corporation Law of the Commonwealth of Pennsylvania.

WHEREAS conformable to the Charter and Laws of The American Philosophical Society the proposal to accept the Constitution of Pennsylvania and the Nonprofit Corporation Law was heretofore submitted in writing to the members:

Now therefore be it resolved that the said proposal as heretofore submitted be and the same is hereby approved,

And be it further resolved, that the officers of the Society are hereby empowered and directed on its behalf to cause a Certificate of Acceptance to be filed with the Secretary of the Commonwealth in the form required by law, to wit:

CERTIFICATE OF ACCEPTANCE

1. The name of the accepting corporation is The American Philosophical Society held at Philadelphia for promoting useful knowledge.

2. The American Philosophical Society was created by the Act of Assembly approved March 15, 1780, L.B. No. 1, 363.

3. The American Philosophical Society herewith accepts the Constitution of Pennsylvania and the provisions of the Nonprofit Corporation Law.

4. The acceptance made herewith was duly authorized by a meeting of the members called for that purpose, held in Philadelphia on the sixth day of December, 1935.

                                                          President

(SEAL)
Filed this   day of
                             , 1935.   *Assistant Secretary*

_____

Secretary of the Commonwealth.

The matter of the proposed settlement of the claim of certain New Jersey charities to the gas holder at Millville,

New Jersey, under Item 7 of the Will of Walter Wood, deceased, was then brought before the meeting.

The Council's and Finance Committee's recommendation was presented.

Upon hearing this report and recommendation, on motion duly made and seconded it was

Resolved that the proper officers of the Society be authorized and instructed in the name of the Society to execute the said Agreement and pursuant thereto to execute whatever deeds of conveyance or other papers might be necessary to carry out the said Agreement, the properties to be sold by the Society are listed and on file.

The following request was approved by the Society:

The Library Committee of the American Philosophical Society favorably recommends to the Society for action a request from the Department of Botany, British Museum (Natural History), for a set of the Franklin Calendar.

THE DISAPPEARANCE OF PRIMARY CAUDAL BANDS IN THE TAIL OF FUNDULUS AND ITS RELATION TO THE NEUROHUMORAL HYPOTHESIS

G. H. PARKER

(*Read April 19, 1935*)

1. INTRODUCTION

It is well known that a primary caudal band in the tail of the killifish, *Fundulus heteroclitus*, produced by cutting the bundles of small nerves in the axial ray of the band will disappear in a few days provided the fish is kept in an illuminated aquarium with white walls. The method of disappearance of such a band was first described by Mills (1932*a*, 1932*b*) according to whom the band does not disappear as a whole simultaneously, but fades first on its margins after which this change progresses gradually inward till at last the axis of the band, the final part to fade, is reached. This progressive method of disappearance of the band in *Fundulus* has been confirmed (Parker, 1934*a*) and its occurrence in other fishes, such as *Ameiurus nebulosus*, has been pointed out (Parker, 1934*b*).

In none of these instances, however, has a particular primary band in a given living fish been observed closely and continuously to ascertain the exact steps in the disappearance

1

of the band. This has been attempted in the present study
in which the identical region in a primary band in the tail of a
living *Fundulus* has been photographed hour by hour for
comparison. By this means a series of views of the changing
band has been obtained in which the details can be followed
with great accuracy. In such a set of photographs it is even
possible to study the changes in an individual melanophore
from its initial stage with the pigment fully dispersed to that
some two days later when the pigment is fully concentrated.
Such a series of photographs thus offers very unusual oppor-
tunities for the study of these bands and their melanophores,
and enables comparisons hitherto quite impossible. Several
sets of these photographs were obtained. Each set was taken
from the tail of a given live fish placed so accurately under the
microscope that at each exposure exactly the same region was
in the field. For this purpose the microscope had attached
to it a Leica Camera by which snap-shot exposures could be
taken at any moment. For the use of this outfit and for the
making of the photographs I am indebted to Mr. A. A.
Abramowitz.

2. OBSERVATIONS

Of the twenty fin-rays commonly found in the tail of *Fun-
dulus* the extreme dorsal and ventral members of the series are
single unbranched filaments that taper from their bases to
their ends near the free edge of the tail. The rays in the cen-
tral region of the tail branch dichotomously and they may
show as many as three such divisions so that a single stout
ray at the base of the tail may be represented by as many as
eight rays near the posterior edge of that structure. As one
passes from the dorsal or ventral edge of the tail toward its
center all conditions of rays are met with from the unbranched
to the fully branched type. For the greater flexibility of the
tail each ray is composed of a series of pieces separated by
joints much as the vertebral column is (Plate 2).

A transverse section of the tail-fin of *Fundulus* at right
angles to the rays is shown in Fig. 1 (Plate 1). Here the left

side of the tail-fin is above, the right below. The fin-ray, seen in section near the middle of the figure, consists of two folded plates, one left, the other right. The fold in each plate indicates the beginning of the separation of this ray into two, a step which will occur in a region distal to where this section was taken. The two folded plates approximate one another in the middle of the fin but do not unite. The region of nearest approach is represented by a slit which extends lengthwise along the ray and through which blood-vessels and nerves pass in or out between the cavity of the rays and the adjacent tissue. In the cavity of the ray and especially near its axis are to be found numerous small bundles of nerve-fibers and small blood-vessels (Figs. 1 and 4). The skin of the fin consists of a relatively thick, irregular epidermis and of a much more uniform but folded derma (Figs. 1 and 2). The interradial tissue filling the space between the skin on the two sides of the fin and the two adjacent rays (Fig. 1) is loose and open, and well supplied with blood-vessels and with branches of nerves from the cavity of the rays.

Melanophores are located on the inner face of the derma of the interradial regions (Fig. 2). They do not occur immediately below the skin in the radial regions. Here they are located within the ray itself especially next the folds of the ray plate (Figs. 1 and 4) and about the slits between the two plates (Figs. 1 and 3). So far as I am aware all melanophores lie thus in the deeper parts of the fin; apparently the derma and epidermis contain none of these structures.

When the base of a caudal ray is cut through, a process that can be accomplished easily by a one-millimeter dental chisel working against wood, all the nerves and blood-vessels in the ray are severed. The nerves thus cut are the nerves distributed to the ray and its branches if it is a branched ray. Each set of such nerves is limited strictly to a given ray and its branches. There appears to be no overlapping between the nerves that start with a given main ray and those of the next main ray. The blood-vessels of one ray, however, freely anastomose with those of adjacent rays so that after a

ray has been cut, though the ray and its branches are com-
pletely denervated, the blood circulation in its part distal to
the cut is in consequence of these collateral connections es-
sentially normal.   If, however, three or more adjacent rays
are cut, the collateral circulation is interfered with to such an
extent that in a few days the tissue of the region becomes
necrotic and is sloughed off.   As is well known when a single
basal ray is cut in the way just described, the melanophores
over the whole area thus denervated disperse their pigment
and produce a dark streak, the primary caudal band.   This
band will remain for several days in a fish which is kept in an
illuminated white-walled aquarium, a condition under which
the fish as a whole is light-tinted.   But such a band after a
few days blanches and the area of the tail occupied by it
becomes as light as that of the rest of the fish.   It is this
process of blanching as seen in primary bands that forms the
subject matter of this paper.

Plate 2 represents a series of photographs taken from the
identical region of a primary band in the tail of a living
Fundulus and at stages ranging from 40 minutes after the
exciting cut had been made (Fig. 7) to 58 hours and 10 min-
utes after that event (Fig. 12).   The spot on the band which
had been chosen for photographing was one in which the basal
ray is represented by four rays through two dichotomous
branchings and in which a third branching is about to take
place as shown in the rays in the upper part of each figure.
Three of the four rays show this branching clearly, the fourth
one, to the extreme left, being unbranched at this level.   A
comparison of the details in the four rays will show at once
that the several photographs are in agreement.   A good
point of reference is the most deeply cleft ray which shows in
each photograph at the crotch of the cleft a large melano-
phore.   As one progresses over the series this melanophore
shows a gradual concentration of its pigment from the condi-
tion seen shortly after the cut had been made (Fig. 7, 40
minutes) to its maximum concentration (Fig. 11, 10 hours
10 minutes).   In Fig. 12 the pigment of this particular melano-

phore appears to be very slightly more dispersed than it is in
Fig. 11. When the whole series of photographs is compared,
the maximum dispersion of pigment as seen in Fig. 7, the
40-minute stage, is in striking contrast with the full concen-
tration of pigment as seen in Fig. 12, 58 hours 10 minutes.
The transition from one stage to the next ordinarily forms a
simple sequence.

When this transition is closely scrutinized the method of
disappearance of the band as due to the changes in the melano-
phores can be made out. Shortly after the band was formed
(Fig. 7) all the melanophores in it showed a marked dispersion
of pigment and the edge of the band in this respect was found
to be essentially the same as the center. After the band had
reached a stage of approximate blanching (Fig. 12), the pig-
ment of all melanophores, those on the edge as well as those in
the center, was about equally concentrated. Between these
two extremes, however, a stage can be found (Fig. 9, 4 hours
10 minutes) at which the pigment in the melanophores of the
edge is more fully concentrated than that in those of the
center. This condition can be seen by a close comparison of
the melanophores of the central area of the band with those
outside the outermost of the four fin-rays in Fig. 9. This
comparison, however, can be better made by tabulation.

For this purpose the whole band in Fig. 9 was divided into
definite areas, each area containing the same individual
melanophores of which the conditions of pigment dispersion
or concentration were then recorded for the three stages al-
ready indicated. For comparison four conditions in the
pigment of the melanophores were arbitrarily chosen. These
were *full dispersion* of pigment as is well shown in most of the
melanophores in the band in Fig. 7 and as is shown enlarged in
Fig. 6 (Plate 1); *part dispersion* of pigment as seen in most of
the band melanophores in Fig. 8 and enlarged in the central
melanophore in Fig. 5; *stellate* condition where the pigment is
concentrated but with a few short processes, many of the band
melanophores in Fig. 12, and the central melanophore in Fig.
6; and finally the *punctate* condition where the pigment is

concentrated to a central dot as seen in the melanophores beyond the band and to its extreme right or left in Fig. 7. These four arbitrary conditions afford a convenient basis for describing the states of the melanophores in the several stages of the band.

Three areas in the band were chosen for comparison; first, that area which is to the left of the left external ray and which may be designated as the *lateral area;* second, the area between this ray and the next one proceeding toward the axis, the *sub-axial area;* and the *axial area* in the axis of the band and bounded right and left by the two rays nearest this axis. These areas were thus bounded laterally by rays; distal and proximal boundaries were arbitrarily marked by lines drawn transversely to the fin-rays and at specified joints in these rays. With this layout the conditions of the individual melanophores in each area and for each stage of change were then determined by a study of the photographs. A tabulation made on the basis of the statistics thus brought together is given in Table 1.

It will be seen from Table 1 that 40 minutes after the initiating cut had been made the conditions of the pigment in the melanophores of the three areas of the band, lateral, sub-axial, and axial, were much the same (Fig. 7). In all instances the pigment was either fully dispersed or partly dispersed and in not far from the same proportions: dispersed 71 per cent in the lateral area, 82 per cent in the sub-axial, and 79 per cent in the axial. In a corresponding way at 58 hours 10 minutes after the cut had been made all three areas presented essentially the same state. Here the melanophores were either stellate or punctate (Fig. 12), the stellate per cents being 53 for the lateral, 61 for the sub-axial, and 59 for the axial. In other words, at both the early and the late stages of the band the conditions of the pigment in the three areas are essentially the same.

When, however, the intervening stage of 4 hours 10 minutes is examined this uniformity is not found to be present. At this stage the lateral and sub-axial melanophores are

TABLE 1

Condition of the melanophores (pigment fully *dispersed*, D; *partly dispersed*, PD; *stellate*, S; concentrated or *punctate*, P) in three definite areas of a primary band (outside the outermost ray, *lateral;* between this ray and the next one, *sub-axial;* and in the *axial* area) at stages following the initial cut by 40 minutes, 4 hours 10 minutes, and 58 hours 10 minutes expressed in actual counts and in per cents. The melanophores for a given area at different stages are identically the *same* melanophores in each instance; thus in the lateral area the 62 melanophores whose conditions are recorded for 40 minutes after the cut are the identical 62 melanophores whose conditions are noted at 4 hours 10 minutes and at 58 hours 10 minutes after that operation.

Areas	Lateral				Sub-axial				Axial			
States	D	PD	S	P	D	PD	S	P	D	PD	S	P
Actual Counts												
40 m...........	44	18	0	0	42	9	0	0	58	15	0	0
4 h. 10 m.. . .	0	0	52	10	0	0	39	12	0	25	44	4
58 h. 10 m...	0	0	33	29	0	0	31	20	0	0	43	30
In Per Cents												
40 m..... ...	71	29	0	0	82	18	0	0	79	21	0	0
4 h. 10 m...	0	0	84	16	0	0	76	24	0	34	60	6
58 h. 10 m..... . ..	0	0	53	47	0	0	61	39	0	0	59	41

mainly stellate, 84 and 76 per cents respectively, while the axial melanophores are 34 per cent part dispersed, 60 per cent stellate, and only 6 per cent punctate. Evidently at this stage the pigment of the melanophores in the axial area is much more dispersed than it is in the other two areas. In this respect the axial area at this stage is more like what it was at 40 minutes after the cut than the other two areas are, a state which shows clearly when all stages are compared (Fig. 7 to 12) that as the primary band begins to change from one of full depth of tint (Fig. 7) to one nearly blanched (Fig. 12), the change does not affect the whole band simultaneously but progresses from its edges to its axis. This peculiarity of the change was originally observed and recorded by Mills as already stated. It is here fully confirmed and first demonstrated by photographic records.

A second series of such records taken from another living *Fundulus* like that last described is shown in Plate 3 in which the figures are arranged as in Plate 2. In Plate 3 the earliest stage, that of 15 minutes after the cut, is to be seen in Fig. 13 and the latest, 54 hours after the cut, in Fig. 18. An inspection of this series of photographs shows without closer analysis the same conditions as those seen in Plate 2. The similarity of the three areas at the first stage (Fig. 13) and at the last one (Fig. 18) is evident and the greater dispersion of the pigment in the axial area at the intervening stage (Fig. 15) as compared with its conditions in the other two areas at this stage is obvious.

It is clear from the two instances (Plates 2 and 3) that as the pigment of the primary band changes from the dispersed to the concentrated condition in the course of time in a light-tinted fish, this change does not affect the band as a whole simultaneously but begins at the margins and works toward the axis. These detailed observations, therefore, confirm the view that the gradual blanching of a primary caudal band is not due to materials brought to the band by blood and lymph which, as Fig. 1 shows, have access to the whole under surface of the band and would therefore affect it uniformly, but that the operation is a lateral one as though the band were invaded by material coming from the surrounding blanched portion of the tail (Mills, 1932a, 1932b; Parker, 1934a, 1934b). Such a view is entirely in keeping with the neuro-humoral hypothesis (Parker, 1932) and in that sense gives support to this conception.

In the course of these studies many thousands of individual melanophores have been inspected. From time to time two rather striking and exceptional conditions have been noted. They are given in Figs. 5 and 6 (Plate 1) which were taken from preserved material. In one, Fig. 5, a single melanophore is seen with its pigment in a partly dispersed state though it is a member of a general field in which all others are either stellate or punctate in form. In the second instance, Fig. 6, the melanophore is almost punctate though all of its neighbors have fully dispersed pigment. Since these

two instances show conditions of pigment almost the reverse of that in their surroundings it might be supposed that they afforded a serious obstacle to the neurohumoral view. In my opinion they indicate that other factors than the environmental neurohumors play a part in determining the state of a given melanophore. What these factors are it is not easy to say. It is, however, well known that some fish melanophores by appropriate means can be set in pulsation, so to speak, in that they can be made alternately to disperse and concentrate their pigment at a relatively rapid rate. Such an operation implies an intra-melanophoric mechanism which can bring about these changes more or less independently of the environment and which can be excited to a certain degree of independent action. Presumably the exceptional instances just described are cases of this type and in consequence stand out from their environment in this remarkable way. At least they do not seem to me to afford a serious objection to the application of the neurohumoral hypothesis. As a matter of fact they are relatively rare. The vast majority of melanophores react with great consistency and uniformity and follow a plan of operation that is in full agreement with the idea that neurohumors are their chief activators.

3. SUMMARY

1. The disappearance of the primary caudal band of *Fundulus* can be followed with great fullness and exactitude by successive photographs of the identical region of the band at various stages in this change.

2. The band when first formed is homogenous and composed of melanophores all of which are much the same in the completeness of their pigment dispersion. In its last stages its pigment is uniformly concentrated.

3. Between these two extremes the more nearly axial melanophores lag behind those nearer the margin in that their pigment is more fully dispersed than that of the marginal members.

4. This condition is unfavorable to the view that the effective agent is carried by blood and lymph and favorable

to that of a lateral invasion of such an agent, a neurohumor, from the adjacent light-tinted part of the tail.

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4. REFERENCES

MILLS, S. M. 1932a. Neuro-humoral Control of Fish Melanophores. *Pro. Nat. Acad. Sci.*, **18**, 540–543.

MILLS, S. M. 1932b. Evidence for a Neurohumoral Control of Fish Melanophores. *Jour. Exp. Zoöl.*, **64**, 245–255.

PARKER, G. H. 1932. *Humoral Agents in Nervous Activity with Special Reference to Chromatophores.* Cambridge, 79 pp.

PARKER, G. H. 1934a. Cellular Transfer of Substances, Especially Neurohumors. *Jour. Exp. Biol.*, **11**, 81–88.

PARKER, G. H. 1934b. Color Changes of the Catfish *Ameiurus* in Relation to Neurohumors. *Jour. Exp. Zoöl.*, **69**, 199–233.

EXPLANATION OF PLATE 1

All figures on this plate are from *Fundulus heteroclitus.* I am under obligations to Dr. F. M. Carpenter for the photographs.

FIG. 1. Section of the tail-fin of *Fundulus* transverse to the fin-rays. The section includes the whole of one ray and a small part of another. The epidermis on both faces of the fin is darkly stained and variable in thickness. It is continuous over the whole fin. The derma is light-colored, relatively uniform in thickness, often somewhat folded, and very thin over the ray. The fin-ray consists of two opposed, folded plates of firm tissues, one on the left side of the fin (above in the photograph) and the other on the right side (below). The two halves of each plate are firmly united but the two plates are not intimately attached and the open spaces between them allow the passage of blood-vessels and of nerves into and out from the cavity of the ray. The interradial spaces are extremely open and contain only very loose strands of tissue. The melanophores are on the inner face of the derma and within the cavity of the rays especially about the aperture where the two plates of a ray are nearly in contact and at the bend between the two halves of each plate.

FIG. 2. Enlarged view of a section of the skin of the tail-fin. The upper, dark, irregular layer composed of many cells is the epidermis. It is devoid of melanophores. It is subtended by a somewhat folded layer of relatively uniform thickness, the derma. On the inner face of the derma, lower in the figure, are to be seen two melanophores, one near the extreme right, the other near the left of the preparation. Between them are sections of a number of melanophore processes. Below the melanophores is the open interradial tissue.

FIG. 3. Enlarged view of the opening between the two plates of a ray (compare Fig. 1) showing melanophores (black) on the sides of the opening.

FIG. 4. Enlarged view of the inner part of the fold between the two halves of a plate (compare Fig. 1). The upper face of the fold carries several melanophores above which are sections of small bundles of nerves and still higher up about the top of the figure sections of blood-vessels.

FIG. 5. Surface view of the interradial membrane from the tail-fin showing a melanophore with moderately dispersed pigment among others all of which have their pigment well concentrated.

FIG. 6. Surface view of the interradial membrane next a ray (below in the figure) of the tail-fin. One melanophore stands out in contrast with all others in that its pigment is strongly concentrated.

PLATE 1

PLATE 2
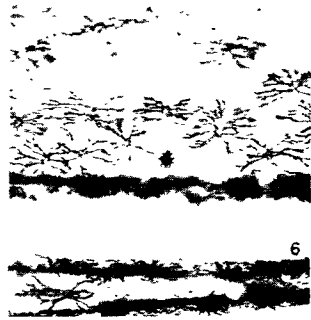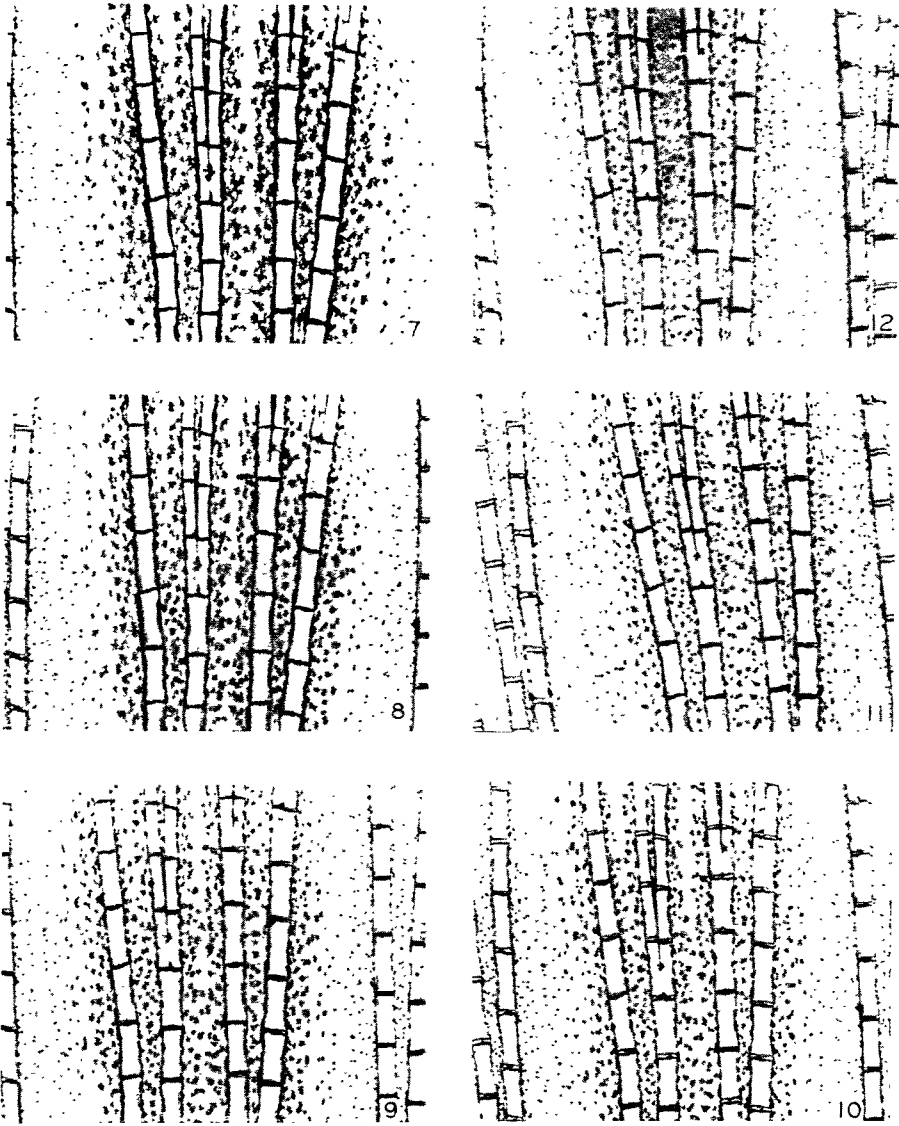
Six views of the *same* region of a primary caudal band in the tail of a living *Fundulus* taken at different times after the initiating cut had been made. The series of views show the method of disappearance of the primary caudal band. The width of the band is clearly seen in Fig. 7 as indicated by the area in which the pigment of the melanophores is dispersed. The band is occupied by the four branches of a single basal fin-ray. I am indebted for these photographs as well as for those on Plate 3 to Mr. A. A. Abramowitz. They were taken at the following intervals after the initial cut had been made:

FIG. 7.	40 minutes
FIG. 8	1 hour 10 minutes.
FIG. 9.	4 hours 10 minutes.
FIG 10.	6 hours 10 minutes
FIG 11	10 hours 10 minutes.
FIG 12.	58 hours 10 minutes.

PLATE 3
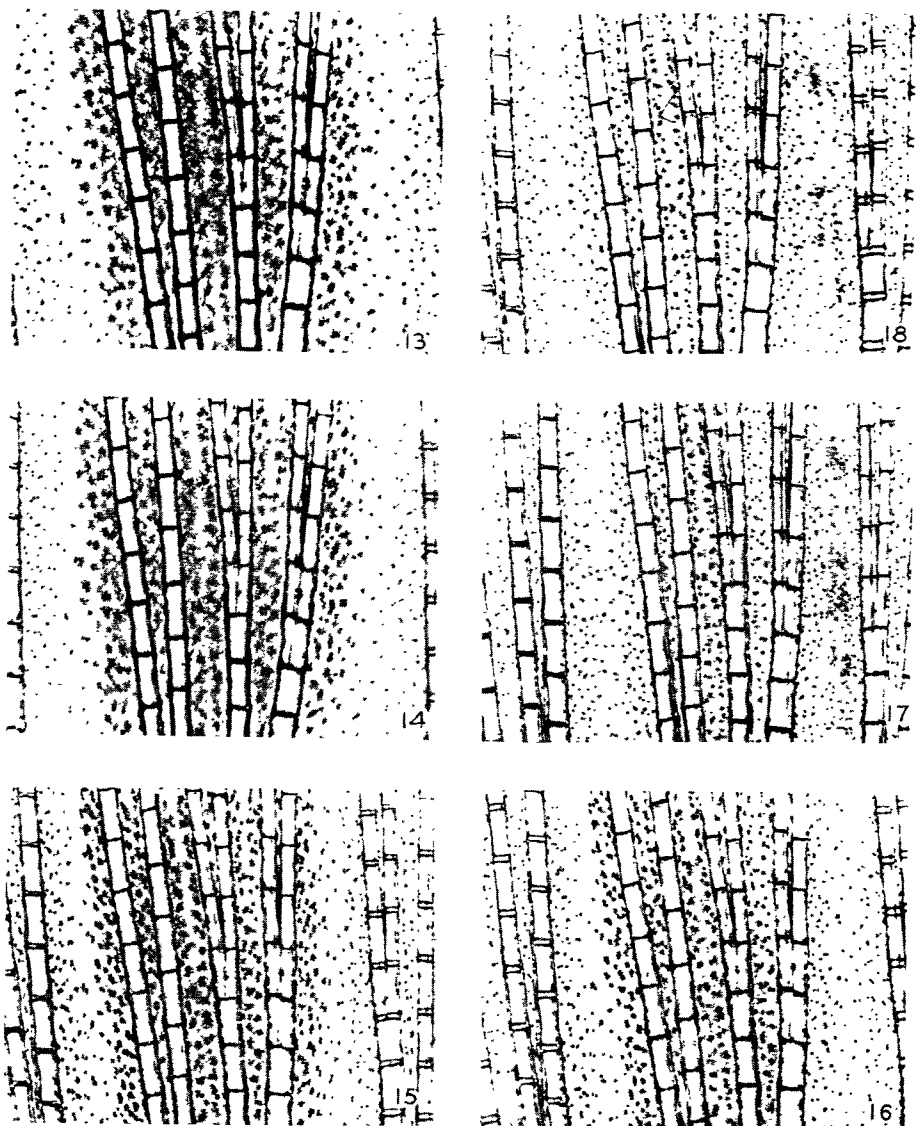
A second series of views taken from the tail of another living *Fundulus* to show the disappearance of a primary caudal band as in Plate 2. The times after the initial cut are as follows:

Fig. 13. 15 minutes.
Fig. 14. 1 hour 45 minutes.
Fig. 15. 6 hours 15 minutes.
Fig. 16. 9 hours 15 minutes.
Fig. 17. 27 hours 15 minutes.
Fig. 18. 54 hours.

ELECTRICAL DISTRIBUTIONS ON CIRCULAR CYLINDERS

E. P. ADAMS

THE problem of determining the electrical distribution on two infinitely long circular cylinders, when charged in any manner, has not received as much attention as the corresponding problem of two spherical conductors. The method of images enables one to give a complete solution of the latter problem. The case of any two cylinders, whether one is external or internal to the other, and when the cylinders have equal and opposite charges, is readily solved by placing two equal and opposite line charges at the inverse points of the cylinders. Some of the problems considered in this paper have been solved by other methods, but it may be useful to treat all of them by a uniform method.

Corresponding problems in the irrotational motion of a perfect fluid in the presence of obstacles in the form of the conductors can also be solved by using the methods and the results that are here obtained. But since it is known that the motion of real fluids departs widely from the motions determined in this way, it may be of greater interest to consider, at present, only the electrostatic problem.

The method which will be used is one that was given by Richmond[1] and applied by him to single cylinders of which an elliptic or hyperbolic contour forms a part. We shall take the plane of the complex variable, $z = x + iy$, as that of the conductors, and consider the plane of another complex variable, $w = u + iv$. We assume that we know the relation

$$w = F(z)$$

by which the whole of the z-plane that is bounded by the given contour can be represented conformally inside an area in the w-plane which is bounded by straight lines intersecting

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[1] *Proceedings London Mathematical Society*, **22**, p. 483, 1923.

at right angles.   The Schwarz-Christoffel method is then used
to transform the area inside the polygon in the w-plane to the
upper half of a t-plane in such a way that the contour in the
w-plane transforms to the real axis of the t-plane; points inside
the contour in the w-plane are then transformed conformally
into points in the upper half of the t-plane.

Let the complex electrostatic potential be taken as

$$\chi = \varphi + i\psi$$

so that φ = constant gives the equipotentials, and ψ = con-
stant the lines of force.   If, by considerations of symmetry,
we know that the contour in the z-plane is made up of equi-
potentials and lines of force, then the area external to the
conductors in the z-plane can be represented conformally upon
the χ-plane; and since the equipotentials and lines of force
intersect at right angles, the area in the χ-plane thus deter-
mined is bounded by straight lines intersecting at right angles.
This area can now, by the Schwarz-Christoffel method, be
transformed to the upper half of the t-plane.   Finally, by
comparing the two transformations to the same t-plane, a
relation

$$\chi = f(z)$$

is derived, which gives the complete solution of the problem.

PART I

Two Circular Cylinders of Different Radii in Contact Along a Common Generator

1. *The w-Plane.*—The transformation by reciprocal radii,

$$w = 2i/z, \tag{1}$$

gives

$$u = \frac{2y}{x^2 + y^2}, \qquad v = \frac{2x}{x^2 + y^2}, \tag{2}$$

and

$$x = \frac{2v}{u^2 + v^2}, \qquad y = \frac{2u}{u^2 + v^2}. \tag{3}$$

v = constant = α gives a circle of radius $1/\alpha$ which is tangent
to the y-axis at the origin; similarly, $v = -\beta$ gives a circle

of radius $1/\beta$, also tangent to the y-axis at the origin, but with its centre to the left of the origin. So we can take the two cylinders to be given by

$$a = 1/\alpha, \qquad b = 1/\beta, \qquad\qquad (4)$$

a and b being the radii of the two cylinders. In a similar way, $u = $ constant gives circles tangent to the x-axis at the origin, with their centres above or below the x-axis according as u is positive or negative.

We suppose the conductor formed by the two cylinders to be freely charged. By symmetry, we need consider only the upper half of the z-plane, shown in Fig. 1.
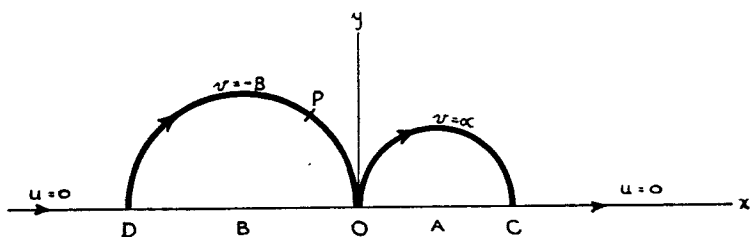
FIG. 1.

Along the x-axis from $-\infty$ to D and from C to $+\infty$, $u = 0$. Along the contour of the semi-circle from D to O, $v = -\beta$, and from O to C, $v = +\alpha$. The point at infinity in the z-plane corresponds to $w = 0$. The w-plane is now shown in Fig. 2. We shall always use the convention that
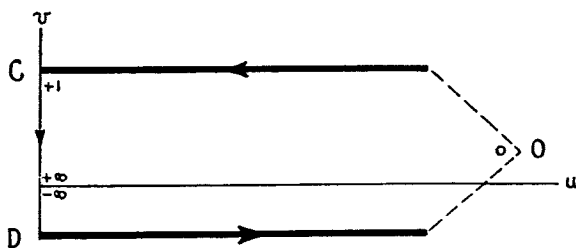
FIG. 2.

in going around a contour in the positive direction, shown by the arrows, the area considered lies to the left. The corre-

sponding real t values at the corners of the semi-infinite rectangle in the x-plane are indicated inside the diagram. The t-plane is represented in Fig. 3.
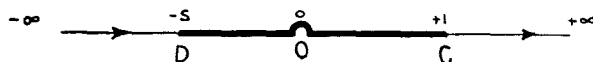
FIG. 3.

Instead of passing through the origin O, where w becomes infinite, we must describe a semi-circle of infinitely small radius.

The Schwarz-Christoffel differential equation for the transformation from the w- to the t-plane is

$$\frac{dw}{dt} = \frac{A}{t\{t - 1 \cdot t + s\}^{\frac{1}{2}}}.$$ (5)

In passing along the semi-circle at O from left to right w increases from $-\beta$ to $+\alpha$. The change in w is therefore $i(\alpha + \beta)$, and by integration along the semi-circle we get

$$A = -i\frac{\alpha + \beta}{\pi}s^{\frac{1}{2}}.$$

The integral of (5), satisfying the conditions that

$$w = i\alpha \quad \text{when } t = 1,$$
$$w = -i\beta \quad \text{when } t = -s,$$
$$w = 0 \quad \text{when } t = \infty,$$

is

$$w = -\frac{2(\alpha + \beta)}{\pi}\sinh^{-1}\left\{\frac{s(1 - t)}{t(1 + s)}\right\}^{\frac{1}{2}} + i\alpha$$ (6)

together with

$$\frac{s}{1 + s} = \sin^2 m\alpha,$$ (7)

where

$$m = \frac{\pi}{2(\alpha + \beta)} = \frac{\pi ab}{2(a + b)}.$$ (8)

From (7) we determine s,

$$s = \tan^2 m\alpha.$$ (9)

Solving (6) for t, we get

$$t = \frac{\sin^2 m\alpha}{\sin^2 m\alpha + \sinh^2 m(w - i\alpha)} \cdot$$

If we substitute for w from (1) we get as the relation between the z- and the t-planes,

$$t = \frac{1 - \cos 2m\alpha}{\cos 2m\left(\dfrac{2}{z} - \alpha\right) - \cos 2m\alpha} \cdot \quad (10)$$

2. *The χ-Plane.*—Let $\varphi = 0$ be taken as the potential of the conductor; then all the potentials in the field will lie between the values $\varphi = 0$ and $\varphi = -\infty$. Let $2Q$ be the charge per unit length of the conductor consisting of the two parallel cylinders in contact. Referring to Fig. 1 we see that the x-axis from $-\infty$ to D is a line of force; choose this to be $\psi = 0$. Also, the x-axis from C to $+\infty$ is a line of force; the constant value of ψ along this portion of the x-axis will now be $4\pi Q$. So all the values of ψ in the χ-plane will lie between $\psi = 0$ and $\psi = 4\pi Q$. Figure 4 represents the χ-plane,
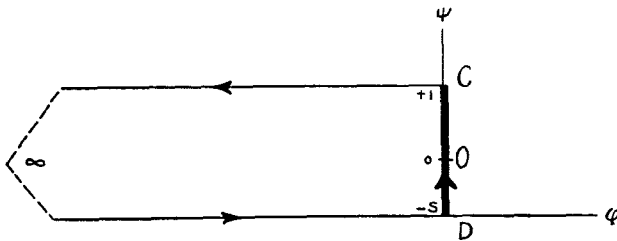
FIG. 4.

with the corresponding t values indicated inside the diagram. The Schwarz-Christoffel transformation is

$$\frac{d\chi}{dt} = \frac{C}{\{t - 1 \cdot t + s\}^{\frac{1}{2}}} \cdot \quad (11)$$

In passing from $t = +\infty$ to $t = -\infty$ along an infinite semicircle χ decreases by $4\pi i Q$. Therefore we get by integration

$$C = -4Q$$

and we find

$$\chi = 4\pi iQ - 4Q \cosh^{-1} \frac{2t - 1 + s}{1 + s}, \qquad (12)$$

which satisfies the conditions

$$\chi = 4\pi iQ \text{ when } t = 1,$$
$$\chi = 0 \text{ when } t = -s.$$

If we solve (12) for t we get

$$t = \frac{1}{1 + \cos 2m\alpha} \{\cos 2m\alpha - \cosh (\chi/4Q)\} \cdot \qquad (13)$$

If the two values of t given by (10) and (13) are equated we get the relation between χ and s that gives the complete solution of the electrostatic problem. It may be shown from the resulting equation that the potential φ, the real part of χ, vanishes over the conductor, and becomes infinite at an infinite distance in the s-plane as $-2Q \log r$.

When $t = 0$ we get, since $\varphi = 0$,

$$\psi = 8m\alpha Q.$$

The difference between the values of χ at $t = 0$ and at $t = -s$ gives 2π times the charge on unit length of the cylinder of radius b; while the difference between the values of χ at $t = 1$ and at $t = 0$ gives 2π times the charge on unit length of the cylinder of radius a. Denoting these charges by Q_b and Q_a, so that $2Q = Q_a + Q_b$ we find, using (4) and (9),

$$Q_a = 2Q \frac{a}{a + b}, \qquad Q_b = 2Q \frac{b}{a + b}.$$

Thus the whole charge on the two cylinders divides between them in the ratio of their radii.

3. *Electric Intensity and Surface Density.*—The electric intensity at any point is given by the modulus of

$$\frac{d\chi}{dz}$$

and the surface density of the charge at any point of a conductor by

$$\sigma = \frac{1}{4\pi}\left|\frac{d\chi}{dz}\right|.$$

Now we can write

$$\frac{d\chi}{dz} = \frac{d\chi}{dt}\frac{dt}{dw}\frac{dw}{dz}. \tag{14}$$

Using the values from (1), (5), and (11), we get

$$\frac{d\chi}{dz} = -\frac{8\pi Q \sin 2m\alpha}{\alpha + \beta} z^{-2}\left\{\cos 2m\left(\frac{2}{z} - \alpha\right) - \cos 2m\alpha\right\}^{-1}. \tag{15}$$

If we put

$$z = re^{i\theta},$$

where r is the radius vector drawn from the origin O, and θ the angle that the radius vector makes with the axis, and then take the modulus of the resulting expression, we get the real electric intensity at any point of the z-plane external to the conductors; also the direction of the electric intensity can be found. The resulting expressions will not be quoted, but we shall proceed to get the surface density at any point of the conductors.

On the cylinder of radius a,

$$r = 2a \cos \theta$$

and the surface density as found from (14) is

$$\sigma_a = \frac{bQ \sin (2m/a)}{2a(a + b) \cos^2 \theta}\left\{\cosh\left(\frac{2m}{a}\tan \theta\right) - \cos\frac{2m}{a}\right\}^{-1}. \tag{16}$$

The surface density on the cylinder of radius b is found by interchanging a and b and measuring the angle θ from the extremity D of this cylinder. In these expressions we have

$$ma = \frac{m}{a} = \frac{\pi b}{2(a + b)}.$$

The surface density on each cylinder vanishes when $\theta = \pi/2$,

the line of contact. By integration of (16) over the cylinder of radius a we find

$$Q_a = 2Q \frac{a}{a+b}$$

in agreement with the result obtained before.

If the cylinders have equal radii

$$\sigma = \frac{Q}{4a^2} \sec^2 \theta \, \mathrm{sech} \left(\frac{\pi}{2} \tan \theta \right)$$

and Q is the charge on each cylinder per unit length.

The repulsion per unit length between the two cylinders is given by

$$X = 8\pi a \int_0^{\pi/2} \sigma_a^2 \cos 2\theta \cdot d\theta.$$

$2\pi\sigma_a^2$ is the normal force per unit area, $2ad\theta$ the element of arc, and 2θ the angle between the normal and the x-axis. Using the value of σ_a given by (16) we find

$$X = \frac{4Q^2b}{(a+b)a} \left\{ 1 - \frac{a+b}{b} + \frac{1}{3} \frac{(a+b)^2}{b^2} \right\}.$$

For cylinders of equal radius, a, this reduces to

$$X = \frac{2}{3} \frac{Q^2}{a},$$

where Q is the charge on unit length of each cylinder.

4. *Two Infinitely Long Cylinders in Contact in a Uniform Electric Field Along the Line of Centres.*—We now go on to find the charges induced on the cylinders when they are placed in a uniform electric field, taking first the case when the field at infinity is parallel to the line of centres. The transformation of the z-plane to the t-plane, through the w-plane, is the same as for the freely charged cylinders, but the χ-plane is different. The potential ϕ in the whole field of the z-plane now varies from $-\infty$ to $+\infty$. We take again $\varphi = 0$ on the conductors. The whole x-axis, excluding the portion inter-

cepted by the cylinders, is a line of force, and since there is no charge on the whole on the cylinders, the value of ψ is constant on the two semi-infinite segments; we shall take this constant value as $\psi = 0$. Fig. 5 now shows the χ-plane.
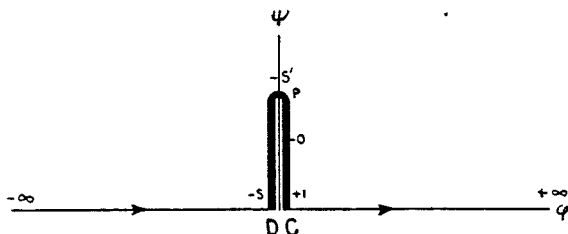
FIG. 5.

Referring to Fig. 1, there will be one line of force that meets the conductor at the point P which separates the positive induced charge to the left from the negative induced charge to the right.   The corresponding t-value for this point is taken as $-s'$.   We assume that this point lies on the larger cylinder, and it will be shown that this is always the case.

The χ-plane is now transformed to the t-plane by the relation

$$\frac{d\chi}{dt} = \frac{C(t + s')}{\{t + s \cdot t - 1\}^{\frac{1}{2}}}. \tag{17}$$

It is not altogether obvious that the Schwarz-Christoffel transformation leads directly to (17); for the area in the χ-plane to be transformed to the upper half of the t-plane is not bounded by straight lines forming a polygon.   It may be shown, however, by the method used by Cisotti [1] that the given area in the χ-plane can be transformed to the interior of a unit circle in a ζ-plane, where $\zeta = \xi + i\eta$, in such a way that the contour of the χ-plane transforms to the circumference of the circle.   The interior of this circle can then be transformed to the upper half of the t-plane in such a way that the circumference of the circle transforms to the real axis of the t-plane.   But we can also regard the transformation ex-

[1] Idromeccanica Piana, t. I, p. 39.

pressed by (17) as an experiment; if the resulting relation between χ and z is such that the real part of χ, which is the electrostatic potential, satisfies the given conditions on the conductors and at infinity, then we can be certain that the solution is right whatever the method used to establish it.

Integrating (17) with the conditions

$$\chi = 0 \quad \text{for} \quad t = 1 \quad \text{and} \quad t = -s,$$

gives

$$\chi = C\{t + s \cdot t - 1\}^{\frac{1}{2}}$$

together with

$$s' = \frac{s - 1}{2} = \frac{\tan^2 m\alpha - 1}{2}.$$

If s' is positive, as we have assumed, s must be greater than 1. This implies that b is greater than a, and so the point P necessarily lies upon the cylinder of greater radius.

If $\pm Q$ represent the equal and opposite charges induced on the conductor, then the difference between the values of ψ at $t = 1$ and $t = -s'$ is $2\pi Q$. Thus we find

$$C = 4\pi Q \cos^2 m\alpha.$$

For the charge on the cylinder of radius a we find in a similar way by taking the difference between the values of ψ at $t = 1$ and $t = 0$,

$$Q_a = - Q \sin 2m\alpha. \tag{18}$$

The cylinder of radius b has an equal and opposite charge.

The complex potential may now be written

$$\chi = 2\pi Q \sin 2m\alpha \frac{\sin 2m\left(\dfrac{2}{z} - \alpha\right)}{\cos 2m\left(\dfrac{2}{z} - \alpha\right) - \cos 2m\alpha}. \tag{19}$$

We can put

$$z = re^{i\theta},$$

where θ is the angle the radius vector r makes with the x-axis. On the cylinder of radius a

$$r = 2a \cos \theta$$

and on the cylinder of radius b

$$r = 2b \cos \theta$$

if now θ be measured from D in Fig. 1.   It may easily be shown that the real part of χ vanishes over the two cylinders, and that when r is large it approaches the value

$$\varphi = - \frac{\pi Q \sin 2m\alpha}{2m} x.$$

It therefore follows that the field at infinity is given by

$$F = - \frac{\pi Q \sin 2m\alpha}{2m}$$

and this determines the induced charges, $\pm Q$.   Our solution (19) therefore satisfies all the conditions of the problem.

The electric intensity at any point of the z-plane is given by

$$R = \left| \frac{d\chi}{dz} \right|.$$

This may be found from (19), or by use of the relation (14) with the values given in (5) and (17).   The result is

$$\frac{d\chi}{dz} = - 16m^2 F \frac{1 - \cos 2m\alpha \cos 2m \left(\frac{2}{z} - \alpha \right)}{z^2 \left\{ \cos 2m \left(\frac{2}{z} - \alpha \right) - \cos 2m\alpha \right\}^2}.$$

When z approaches ∞ the denominator approaches $\infty \cdot 0$. But we find

$$\text{Limit}_{z \to \infty} \left\{ \cos 2m \left(\frac{2}{z} - \alpha \right) - \cos 2m\alpha \right\} = 4m \sin 2m\alpha,$$

so that

$$\text{Limit}_{z \to \infty} \left| \frac{d\chi}{dz} \right| = F.$$

The surface density of the charge on the cylinder of radius a may now be expressed:

$$\sigma_a = - \frac{\pi b^2 F}{4(a+b)^2} \sec^2 \theta \frac{1 - \cos 2m\alpha \cosh (2m\alpha \tan \theta)}{\{\cosh (2m\alpha \tan \theta) - \cos 2m\alpha\}^2}, \quad (20)$$

while that on the cylinder of radius b is obtained by reversing the sign, interchanging a, b and α, β, and measuring θ from the extremity D of that cylinder. If $b > a$, $\cos 2m\alpha$ is negative and σ_a vanishes only for $\theta = \pi/2$. But in this case, $\cos 2m\beta$ is positive and so σ_b will vanish, besides for $\theta = \pi/2$, for a value of θ determined by the relation

$$\cosh \left(\frac{\pi a}{a+b} \tan \theta \right) = \sec \frac{\pi a}{a+b}. \quad (21)$$

In particular, if $b = 2a$, we find that the position of the point P is determined by the angle θ given by

$$\cosh \left(\frac{\pi}{3} \tan \theta \right) = 2.$$

So $\theta = 51° 30'$ approximately. The point of equilibrium P lies between $\theta = \pi/4$, when $a = 0$, the case of a single cylinder in a uniform field, and $\theta = \pi/2$, when the two cylinders have equal radii.

5. *A Circular Cylinder in Contact with an Infinite Plane.*— If the radii of the two cylinders are equal the expression for the surface density on either cylinder becomes

$$\sigma = \frac{\pi F}{16} \sec^2 \theta \operatorname{sech}^2 \left(\frac{\pi}{2} \tan \theta \right) \quad (22)$$

with equal and opposite values for the two cylinders. But now the infinite plane $x = 0$ is an equipotential. We therefore have the solution for a freely charged circular cylinder standing on a conducting plane which has a breadth large compared with the radius of the cylinder. The surface density on the plane is found to be

$$\sigma = \frac{\pi F a^2}{4y^2} \operatorname{csch}^2 \frac{\pi a}{y},$$

where y is the distance on plane measured from the origin O. When y approaches ∞, σ approaches the value $F/4\pi$, its known

value for a charged plane.   The whole charge per unit length on a strip of width $2a$, symmetrically situated with respect to the cylinder, is

$$\frac{Fa}{2}(\coth \pi - 1) = 0.0038Q,$$

where Q is the charge on unit length of the cylinder.   Our result for a cylinder standing on a plane agrees with that found by Bateman[1] in a different way.

6. *Two Infinitely Long Circular Cylinders in Contact in a Uniform Field Perpendicular to the Line of Centres.*—In this case the whole x-axis, including the contour of the cylinders, may be taken as having the potential o.   Then the χ-plane will simply be the t-plane turned through a right angle.   We can therefore write

$$\chi = iDt,$$

where D is a constant.   The equal and opposite charges induced on the cylinder of radius a, or $\pm Q_a$, are given by

$$4\pi Q_a = \psi(t = 1) - \psi(t = 0),$$

or

$$Q_a = D/4\pi.$$

Similarly,

$$4\pi Q_b = \psi(t = 0) - \psi(t = -s),$$

or

$$Q_b = \frac{Ds}{4\pi} = \frac{D\tan^2 m\alpha}{4\pi},$$

so that

$$Q = Q_a + Q_b = \frac{D\sec^2 m\alpha}{4\pi}.$$

The complex potential is now

$$\chi = \frac{2\pi i Q \sin^2 2m\alpha}{\cos 2m\left(\dfrac{2}{z} + \beta\right) - \cos 2m\beta}$$

[1] *Partial Differential Equations of Mathematical Physics*, p. 263.

and

$$\frac{d\chi}{dz} = -8\pi iQ \frac{m \sin^2 2m\alpha \sin 2m\left(\frac{2}{z}+\beta\right)}{z^2 \left\{\cos 2m\left(\frac{2}{z}+\beta\right) - \cos 2m\beta\right\}^2} \cdot$$

When z approaches infinity the electric intensity must approach F. So we get

$$Q = \frac{abF}{a+b} \csc \frac{\pi a}{a+b} \cdot$$

The same result follows by taking the real part of χ as z approaches infinity. We now have for the charges induced upon the two cylinders,

$$Q_a = \frac{abF}{2(a+b)} \tan \frac{\pi a}{2(a+b)},$$

$$Q_b = \frac{abF}{2(a+b)} \tan \frac{\pi b}{2(a+b)} \cdot$$

The surface density on the cylinder of radius a is given by

$$\sigma_a = \frac{Qm \sin^2 2m\alpha}{2a^2 \cos^2 \theta} \frac{\sinh (2m\alpha \tan \theta)}{\{\cosh (2m\alpha \tan \theta) + \cos 2m\beta\}^2} \cdot \quad (23)$$

7. *Two Half-Cylinders Standing on a Freely Charged Conducting Plane.*—Since the plane $y = 0$ is at zero potential, it may be taken as a conducting plane, and we now have the solution for the problem of a freely charged plane upon which two long half-cylinders stand (Fig. 6). The surface density
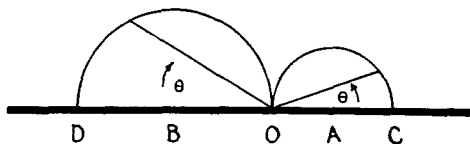
FIG. 6.

at any point of the cylinders is given by (21) and the corresponding expression for the cylinder of radius b. On the

plane the surface density is, at a distance x from the origin,

$$\sigma = \frac{4Fm^2}{\pi} \frac{\sin 2m\alpha \sin 2m\left(\frac{2}{x}+\frac{1}{b}\right)}{x^2\left\{\cos 2m\left(\frac{2}{x}+\frac{1}{b}\right) - \cos\frac{2m}{b}\right\}^2}. \qquad (24)$$

For large x this approaches the known value $F/4\pi$.

<center>PART II</center>

<center>Two Unequal Parallel Cylinders at Any Distance Apart</center>

8. The problem of determining the distribution on two equal, infinitely long parallel cylinders, carrying any charges, was solved by Whipple.[1] His method depends upon the selection of a transformation which, from the properties of the elliptic functions, will lead to a result that satisfies all the conditions of the problem. It is the great advantage of the method that is used here that the required transformation may be found in the simplest form. Love[2] gave a solution of the problem of two cylinders of different radii by using a method of inversion from the solution of the problem of two infinitely long strips. The method here employed leads to the desired result very directly, and, in addition, readily solves a number of related problems when the conductors are placed in a uniform electric field.

9. *Transformation of the z- to the w-Plane.*—The transformation from the z- to the w-plane that we shall use is given by

$$z = if \cot\frac{1}{2}w,$$

or

$$e^{iw} = \frac{z-f}{z+f}. \qquad (25)$$

[1] *Proceedings Royal Society*, **96**, p. 465, 1920.

[2] *Proceedings London Mathematical Society*, **22**, p. 337, 1923.

The curves u = constant are circles, with their centres on the y-axis, and all passing through the two inverse points F, F' on the x-axis, $x = \pm f$ (Fig. 7). u is the angle subtended by
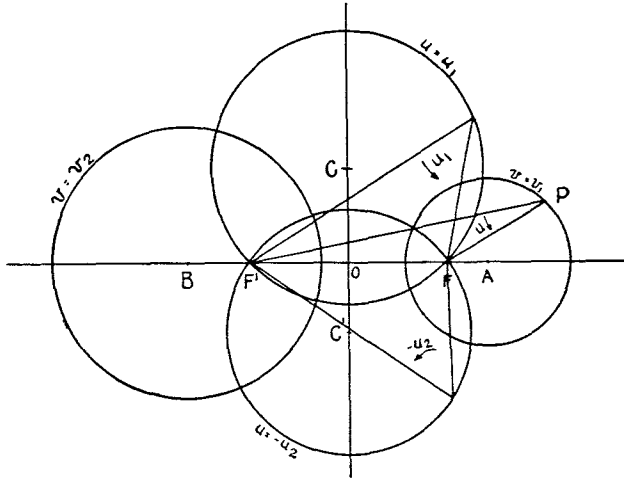
FIG. 7.

FF' at any point of one of these circles. The curves v = constant are also circles, with their centres on the x-axis. If P is any point upon one of these circles, then

$$v = \log \frac{F'P}{FP}.$$

If the values of v corresponding to two of the circles have the same sign then one circle is inside the other, while if they have opposite signs the circles are external to each other; one has its centre on the positive x-axis and the other its centre upon the negative x-axis. We shall accordingly take

$$v = \alpha, \qquad v = -\beta,$$

where α and β are positive, for our two circles. The distances of the centres of the two circles from the origin O are

$$OA = f \coth \alpha,$$
$$OB = f \coth \beta,$$

and thus the distance between their centres is

$$2d = f(\coth \alpha + \coth \beta). \qquad (26)$$

If a, b are the radii of the two circles,

$$\begin{aligned} a &= f \operatorname{cosech} \alpha, \\ b &= f \operatorname{cosech} \beta. \end{aligned} \qquad (27)$$

If x, y are the coordinates of any point in the z-plane defined by u, v,

$$\left.\begin{aligned} x &= \frac{f \sinh v}{\cosh v - \cos u}, \\[2mm] y &= \frac{f \sin u}{\cosh v - \cos u}. \end{aligned}\right\} \qquad (28)$$

The element of arc of any circle, $v = $ constant, is

$$ds = \frac{f\,du}{\cosh v - \cos u} \qquad (29)$$

and the angle, φ, between the normal to any circle, $v = $ constant, and the x-axis is given by

$$\cos \varphi = \frac{\cosh v \cos u - 1}{\cosh v - \cos u}. \qquad (30)$$

10. *The w-Plane.*—The upper half of the z-plane which, by symmetry, is all that we need to consider, is shown in Fig. 8.
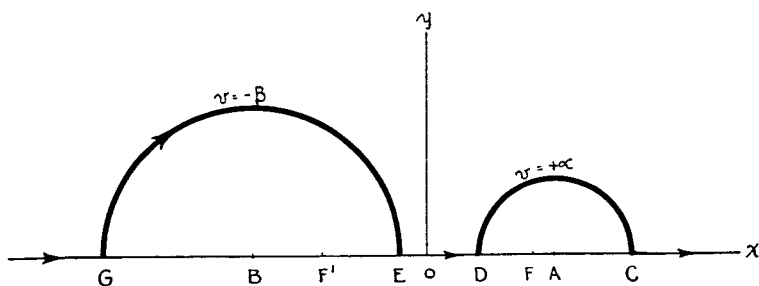
Fig. 8.

Along the x-axis from $-\infty$ to G, $u = 0$, and v decreases from o to $-\beta$. Along the semi-circle GE, $v = -\beta$ and u increases from o to π. Along the x-axis from E to D, $u = \pi$, and v

increases from $-\beta$ to $+\alpha$.   Along the semi-circle DC, $v = \alpha$, and u diminishes from π to 0.   Along the x-axis from C to $+\infty$, $u = 0$, and v diminishes from α to 0.   The w-plane is now shown in Fig. 9.   All points in the upper half of the
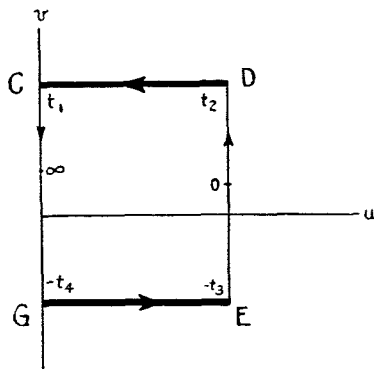
FIG. 9.

s-plane external to the two conductors are conformally represented inside the rectangle in the w-plane.

We take four real quantities,

$$+\infty > t_1 > t_2 > -t_3 > -t_4 > -\infty$$

and transform from the w-plane to the t-plane so that the four corners of the rectangle, G, E, D, C, are represented by the points

$$-t_4, \; -t_3, \; t_2, \; t_1$$

on the real axis of the t-plane.   Then the Schwarz-Christoffel transformation gives

$$\frac{dw}{dt} = \frac{A}{\{t - t_1 \cdot t - t_2 \cdot t + t_3 \cdot t + t_4\}^{\frac{1}{2}}}.$$

We are at liberty to choose three corresponding points in the w- and t-planes.   We shall first choose two relations among the four t-values in such a way that no odd powers of t appear under the radical.   This leads to

$$t_1 + t_2 = t_3 + t_4$$

and

$$t_1 t_2 = t_3 t_4.$$

Accordingly, we take

$$t_2 = t_3,$$
$$t_1 = t_4.$$

We now have

$$\frac{dx}{dt} = \frac{A}{\{t^2 - t_1^2 \cdot t^2 - t_2^2\}}. \tag{31}$$

Integrate by putting

$$t = t_2 \, sn \, \lambda$$

and we get

$$x = -\frac{A}{t_1}\lambda + B. \tag{32}$$

The modulus, k, of the elliptic functions, is given by

$$k = t_2/t_1.$$

Since $t_1 > t_2$, k is less than unity. We can now take $t_2 = 1$, and $t_1 = 1/k$. This is the third relation between the four real t-values.

We now have corresponding values of our variables shown in the following scheme:

$$
\begin{array}{ccccc}
t = & t_1 & t_2 & -t_2 & -t_1 \\
sn\,\lambda = & 1/k & 1 & -1 & -1/k \\
\lambda = & K + iK' & K & -K & -K + iK' \\
x = & i\alpha & \pi + i\alpha & \pi - i\beta & -i\beta
\end{array} \right\} . \tag{33}
$$

K and K' are the complete elliptic integrals of the first kind to the moduli k and k' respectively.

Substituting these corresponding values in (32) we find

$$A = -\frac{i\pi}{K'k},$$

$$B = \pi + i\alpha - \frac{i\pi K}{K'},$$

and

$$\frac{\pi K}{K'} = \frac{\alpha + \beta}{2}. \tag{34}$$

We therefore have, as the relation between x and $t = sn\,\lambda$,

$$x = \frac{i\pi}{K'}\lambda + \pi + \frac{1}{2}i(\alpha - \beta)$$

or

$$\lambda = -i\frac{2Kx}{\alpha + \beta} - \delta + iK', \qquad\qquad (35)$$

where

$$\delta = K\frac{\alpha - \beta}{\alpha + \beta}. \qquad\qquad (36)$$

The infinitely distant point in the z-plane transforms to $x = 0$. Let $t = -r$ be the corresponding real t value, and take λ' so that $-r = sn\,\lambda'$. We then have from (35) with $x = 0$,

$$1/r = ksn\delta. \qquad\qquad (37)$$

$t = 0$ corresponds to $sn\,\lambda = 0$, or $\lambda = 0$. If x_0 is the corresponding value of x,

$$x_0 = \pi + \tfrac{1}{2}i(\alpha - \beta).$$

Therefore $t = 0$ lies on the segment of the x-axis between the two cylinders.

When $t = \infty$, we have $\lambda = iK'$, and so

$$x = \tfrac{1}{2}i(\alpha - \beta)$$

or

$$u = 0, \qquad v = \tfrac{1}{2}(\alpha - \beta).$$

If $b > a$, $\alpha > \beta$, and v is positive. The point $t = \infty$ therefore lies above the u-axis, as shown in Fig. 9.

The origin of coördinates in the z-plane, $z = x = y = 0$, corresponds to $u = \pi$, $v = 0$ in the w-plane, and the corresponding value of t is $t = -sn\,\delta$.

11. *Dimensions.*—The simplest way to introduce the dimensions of the cylinders and their distance apart into our calculations is to assume definite arbitrary values for k, where $k = \sin\theta$, θ being the modular angle, and the quantity δ in (36). Legendre's Table I gives the values of K and K' for

TABLE I

δ	θ	0°.1	0°.5	1°.0	5°.0	10°.0	20°.0	30°.0
0°	α β	0.638	0.805	0.908	1.290	1.577	2.032	2.455
10°	α	0.709	0.895	1.009	1.433	1.751	2.251	2.710
	β	0.567	0.716	0.807	1.147	1.403	1.813	2.202
20°	α	0.780	0.984	1.110	1.506	1.925	2.470	2.964
	β	0.496	0.626	0.706	1.004	1.174	1.594	1.947
30°	α	0.850	1.074	1.211	1.720	2.098	2.689	3.218
	β	0.425	0.537	0.605	0.861	1.055	1.375	1.693

every tenth of a degree from $\theta = 0$ to $\theta = 90°$. And so (34) and (36) give

$$\alpha = \frac{\pi}{K'}(K + \delta),$$
$$\beta = \frac{\pi}{K'}(K - \delta). \tag{38}$$

Having thus determined α and β, (24) and (25) give

$$\frac{b}{a} = \frac{\sinh \alpha}{\sinh \beta},$$

$$\frac{2d}{a} = (\coth \alpha + \coth \beta) \sinh \alpha,$$

$$\frac{2d}{b} = (\coth \alpha + \coth \beta) \sinh \beta.$$

For equal cylinders, $\delta = 0$, $\alpha = \beta$.

Table I gives a few values of α and β corresponding to assumed values of k and δ; Table II gives the values of b/a and $2d/a$ derived from these.

12. *The χ-Plane.*—We shall first take the two cylinders at the same potential, $\varphi = 0$. Then all the potentials in the z-plane will lie between $\varphi = 0$ and $\varphi = -\infty$. Referring to Fig. 8 we see that the x-axis from $-\infty$ to G is a line of force. Let this be taken as $\psi = 0$. φ increases from $-\infty$ to 0 along

TABLE II

δ	θ	0°.1	0°.5	1°.0	5°.0	10°.0	20°.0	30°.0
0°	b/a	1	1	1	1	1	1	1
	2d/a	2.421	2.684	2.882	3.908	5.047	7.760	11.732
10°	b/a	1.288	1.309	1.325	1.396	1.462	1.574	1.675
	2d/a	2.762	3.087	3.334	4.635	6.120	9.725	15.215
20°	b/a	1.668	1.723	1.765	1.814	2.293	2.487	2.815
	2d/a	3.197	3.597	3.906	5.174	7.564	12.328	19.777
30°	b/a	2.183	2.295	2.381	2.782	3.181	3.957	4.758
	2d/a	3.767	4.268	4.657	6.761	9.257	15.718	25.902

this portion of the x-axis. Along the semi-circle from G to E, φ is constant, equal to 0, and ψ increases from 0 at G to $2\pi Q_b$ at E where Q_b is the charge on unit length of the cylinder of radius b. The segment ED of the x-axis is a line of force along which ψ has the constant value $2\pi Q_b$, while φ first decreases to a minimum and then increases to 0 at D. Along the semi-circle DC, φ is 0 while ψ increases from $2\pi Q_b$ to $2\pi(Q_a + Q_b)$, Q_a being the charge on unit length of the cylinder of radius a. Finally, along the x-axis from C to $+\infty$, ψ retains this last constant value and φ diminishes from 0 at C to $-\infty$. The χ-plane is now represented in Fig. 10. We

FIG. 10.

shall take $t = -s$ as the value of t at the point on the segment ED where the potential has its minimum value. The Schwarz-Christoffel transformation now gives

$$\frac{d\chi}{dt} = \frac{C(t + s)}{(t + r)\{t^2 - 1 \cdot t^2 - 1/k^2\}^{\frac{1}{2}}}. \qquad (40)$$

$t = -r$, where r is given by (37), is the value of t correspond-
ing to the point at infinity in the z-plane. In going through
$t = -r$ along a semi-circle of infinitely small radius, χ dimin-
ishes by $2\pi i(Q_a + Q_b)$. By integration, we find for the value
of the constant C,

$$C = -\frac{2(Q_a + Q_b)\,cn\,\delta\,dn\,\delta}{k\,sn\,\delta(1 - sk\,sn\,\delta)}.$$

The integral (40) may be resolved into the three integrals,

$$\chi = k^3 C\,sn^2\,\delta\left(1 - \frac{s}{r}\right)\int \frac{t^2 dt}{(1 - k^2 sn^2\,\delta\cdot t^2)\{1 - k^2 t^2 \cdot 1 - t^2\}^{\frac{1}{2}}}$$

$$- kC\frac{s}{r}\int \frac{dt}{\{1 - k^2 t^2 \cdot 1 - t^2\}^{\frac{1}{2}}}$$

$$+ C(s - r)k\int \frac{t\,dt}{(r^2 - t^2)\{1 - k^2 t^2 \cdot 1 - t^2\}^{\frac{1}{2}}} + D.$$

The first is an elliptic integral of the III kind, and by writing
$t = sn\,\lambda$ may be expressed in terms of Jacobi's Π-function,

$$\Pi(\lambda, \delta, k) = k^2\,sn\,\delta\,cn\,\delta\,dn\,\delta\int_0^\lambda \frac{sn^2\,\lambda d\lambda}{1 - k^2\,sn^2\,\delta\,sn^2\,\lambda}. \quad (41)$$

The second is an elliptic integral of the I kind, and the third
integral is algebraic. We therefore find

$$\chi = kC(1 - sk\,sn\,\delta)\frac{sn\,\delta}{cn\,\delta\,dn\,\delta}\Pi(\lambda, \delta, k) + \frac{ksC}{r}\lambda$$

$$- \frac{iC(s - r)k^2\,sn^2\,\delta}{cn\,\delta\,dn\,\delta}\sin^{-1}\left\{\frac{r^2 - 1}{1 - k^2}\frac{1 - k^2 t^2}{r^2 - t^2}\right\}^{\frac{1}{2}} + D, \quad (42)$$

where D is a constant. This is the solution for $1 \leqslant t^2 \leqslant 1/k^2$
if, for $t = +1/k$, $\sin^{-1} o = o$, and for $t = -1/k$, $\sin^{-1} o = \pi$,
with the same value for the constant D.

To determine the constants, we have the following scheme:

$t =$	$1/k$	1	-1	$-1/k$
$\lambda =$	$K+iK'$	K	$-K$	$-K+iK'$
$\Pi = (K+iK')Z(\delta)$		$KZ(\delta)$	$-KZ(\delta)$	$(-K+iK')Z(\delta)$
	$+\dfrac{i\pi\delta}{2K}$			$+\dfrac{i\pi\delta}{2K}$ (43)
$\chi = 2\pi i(Q_a+Q_b)$		$2\pi iQ_b$	$2\pi iQ_b$	0

$Z(\delta)$ is Jacobi's Zeta Function, the periodic part of the elliptic integral of the II kind.

On substituting these corresponding values, we get

$$sk = \frac{Z(\delta)}{sn\ \delta\ Z(\delta)\ +\ cn\ \delta\ dn\ \delta}, \tag{44}$$

which determines s. We find also

$$\frac{Q_a}{Q_a + Q_b} = \frac{1}{2}\left(1 - \frac{\delta}{K}\right)$$

or, using (36),

$$\frac{Q_a}{Q_a + Q_b} = \frac{\beta}{\alpha + \beta}$$

and

$$\frac{Q_b}{Q_a + Q_b} = \frac{\alpha}{\alpha + \beta},$$

$$\frac{Q_a}{Q_b} = \frac{\beta}{\alpha}. \tag{45}$$

This gives the ratio in which the total charge divides between the two cylinders at the same potential.

When the cylinders approach each other and come into contact, θ, the modular angle, becomes 0, K becomes $\pi/2$ and K' becomes infinite. So, by (34), α and β both approach 0. f also approaches 0 in this case, and by (25) we have

$$a = f/\alpha,$$
$$b = f/\beta.$$

Therefore by (45) we have

$$\frac{Q_a}{Q_b} = \frac{a}{b},$$

as we found in Part I for the two cylinders in contact. Furthermore, (24) now gives

$$2d = a + b.$$

The complex potential, χ, in the general case when a and b

are unequal can now be written

$$\chi = -2(Q_a + Q_b)\left\{ \Pi(\lambda, \delta, k) - Z(\delta)\lambda - i\pi\left(1 + \frac{\delta}{2K}\right) \right.$$
$$\left. + i\sin^{-1}\frac{dn\,\delta\,dn\,\lambda}{k'\{1 - k^2\,sn^2\,\delta\,sn^2\,\lambda\}^{\frac{1}{2}}} \right\}, \quad (46)$$

λ is given by (35), and x, expressed as a function of z, by (24).

13. *Electric Intensity and Surface Density.*—From the relation

$$\frac{d\chi}{dz} = \frac{d\chi}{dt}\frac{dt}{dw}\frac{dw}{dz}$$

we find

$$\frac{d\chi}{dz} = \frac{2(Q_a + Q_b)K'}{\pi f}\left\{ Z(\delta) \right.$$
$$\left. - \frac{cn\,\delta\,dn\,\delta}{sn\left(i\,\dfrac{K'w}{\pi} + \delta\right) - sn\,\delta} \right\}(1 - \cos w).$$

It will be convenient to have for future reference the definite expressions for λ, $sn\,\lambda$, $cn\,\lambda$, and $dn\,\lambda$ on the cylinders as well as on the plane $y = 0$. These are:

On the cylinder of radius a

$$\lambda_a = K + iK' - iu',$$

$$sn\,\lambda_a = \frac{1}{k}dn(u', k'),$$

$$\quad (47)$$

$$cn\,\lambda_a = -i\frac{k'}{k}cn(u', k'),$$

$$dn\,\lambda_a = k'\,sn(u', k').$$

On the cylinder of radius b

$$\lambda_b = -K + iK' - iu',$$
$$sn\,\lambda_b = -sn\,\lambda_a,$$
$$cn\,\lambda_b = -cn\,\lambda_a, \quad (48)$$
$$dn\,\lambda_b = dn\,\lambda_a.$$

On the plane $y = 0$ when $u = 0$

$$\lambda = iK' + v',$$

$$sn\,\lambda = \frac{1}{k\,sn\,v'},$$

$$cn\,\lambda = -\frac{i}{k}\frac{dn\,v'}{sn\,v'}, \qquad (49)$$

$$dn\,\lambda = -i\frac{cn\,v'}{sn\,v'}.$$

On the plane $y = 0$ when $u = \pi$

$$\lambda = v'. \qquad (50)$$

In these expressions we have used for abbreviation

$$\left.\begin{array}{l} u' = \dfrac{K'u}{\pi} = \dfrac{2Ku}{\alpha + \beta}, \\[3mm] v' = \dfrac{K'v}{\pi} - \delta = \dfrac{2Kv}{\alpha + \beta} - \delta. \end{array}\right\} \qquad (51)$$

The modulus of the elliptic functions is always k unless the complementary modulus, k', is expressly indicated.

The surface density on the cylinder of radius a, given by

$$\sigma_a = \frac{1}{4\pi}\left|\frac{d\chi}{dz}\right|_a,$$

can now be expressed

$$\sigma_a = \frac{(Q_a + Q_b)K'}{2\pi^2 f}\left\{ Z(\delta) \right.$$

$$\left. + \frac{cn\,\delta\,dn\,\delta\,dn(u', k')}{1 + sn\,\delta\,dn(u', k')}\right\}(\cosh\alpha - \cos u) \quad (52)$$

with a corresponding expression for σ_b. On integration over the cylinder, using the value (26) for ds, we find

$$Q_a = \frac{1}{2}(Q_a + Q_b)\left(1 - \frac{\delta}{K}\right)$$

just as was found before.

At a great distance from the cylinders w approaches o, and we find

$$\underset{u \to 0}{\text{Limit}} \frac{cn\, \delta\, dn\, \delta(1 - \cos w)}{sn\left(\dfrac{iK'w}{\pi} + \delta\right) - sn\, \delta} = -\frac{1}{2}\frac{i\pi w}{K'}.$$

We therefore get

$$\underset{u \to 0}{\text{Limit}}\left|\frac{d\chi}{dz}\right| = (Q_a + Q_b)\frac{w}{f}.$$

From (24) and writing $z = re^{i\theta}$, we have

$$\underset{u \to 0}{\text{Limit}}\left|\frac{d\chi}{dz}\right| = \frac{2(Q_a + Q_b)}{r}.$$

Thus this necessary condition is satisfied by our solution.

14. *Cylinders of Equal Radius.*—When the radii of the two cylinders are equal, $\delta = 0$, $Q_a = Q_b = Q$, and we get the following expressions for the complex potential χ, and the surface density, σ_a:

$$\chi = -4iQ\left\{\sin^{-1}\frac{dn\,\lambda}{k'} - \pi\right\},$$

$$\sigma_a = \frac{QK'}{\pi^2 f} dn(u', k')(\cosh\alpha - \cos u).$$

The repulsion between the two equal cylinders is given by

$$X = 4\pi f \int_0^\pi \frac{\sigma_a^2 \cos\varphi\, du}{\cosh\alpha - \cos u},$$

using (27) for $\cos\varphi$. On carrying out the integration we find

$$X = \frac{2Q^2}{\pi^2 f}\{\pi^2 \coth\alpha - 2E'K'\}.$$

Q is the charge on unit length of each cylinder, and E' is the complete elliptic integral of the II kind to the modulus k'. The values of E and E' are given in Legendre's Table I together with K and K'.

For the cylinders far apart, the modular angle θ approaches $\pi/2$, and $K' = E' = \pi/2$. The repulsion between the cylinders therefore approaches the value

$$X = Q^2/f.$$

When the cylinders approach each other and come into contact, the modular angle approaches o. Then $K = \pi/2$, $K' = \infty$, $E' = 1$. By (34) when $\alpha = \beta$,

$$\frac{\pi K}{K'} = \alpha$$

and so α approaches o. For small α,

$$\coth \alpha = \frac{1}{\alpha} + \frac{\alpha}{3}$$

and the repulsion between the cylinders in contact becomes

$$X = 2Q^2/3a,$$

in agreement with the result obtained directly in Part I.

14. *Unequal Cylinders. Any Charges.*—Our solution so far has assumed that the two cylinders are at the same potential and we have found that the ratio of their charges is given by (45). If we now give the cylinders any arbitrary charges, Q_1, Q_2, on the cylinders of radius a and b respectively, the difference of potential between them can be determined. A line charge Q' per unit length placed at the inverse point F in the cylinder of radius a and a line charge $-Q'$ placed at the inverse point F' in the cylinder of radius b makes each cylinder an equipotential surface. The charges on the two cylinders will now be

$$Q_1 = Q_a + Q',$$
$$Q_2 = Q_b - Q'.$$

From these we get

$$Q_1 + Q_2 = Q_a + Q_b$$

and

$$2Q' = (Q_1 - Q_2) - (Q_a - Q_b).$$

Or, by (45),

$$Q' = \frac{Q_1\alpha - Q_2\beta}{\alpha + \beta}. \tag{53}$$

With the charges Q_a and Q_b the difference of potential between the cylinders is o. We can readily find the difference of potential due to the charges $\pm Q'$ by taking a complex potential,

$$\chi' = -iC'w = C'(v - iu).$$

The difference of potential between the cylinders is now

$$V = C'(\alpha + \beta).$$

We also have

$$Q' = C'/2,$$

and so

$$V = 2(Q_1\alpha - Q_2\beta). \tag{54}$$

The surface density on the cylinder of radius a resulting from the charges $\pm Q'$ is

$$\sigma_a' = \frac{Q_1\alpha - Q_2\beta}{2\pi f(\alpha + \beta)} (\cosh \alpha - \cos u),$$

or, by (38),

$$\sigma_a' = \frac{1}{4\pi f} \left\{ Q_1 - Q_2 + \frac{\delta}{K}(Q_1 + Q_2) \right\} (\cosh \alpha - \cos u). \tag{55}$$

If this be added to (49), putting $Q_a + Q_b = Q_1 + Q_2$ we get the surface density on this cylinder when the two cylinders have arbitrary charges Q_1 and Q_2, with a difference of potential given by (54).

The repulsion per unit length between the two equal cylinders with any charges, Q_1 and Q_2, is

$$X = \frac{(Q_1 + Q_2)^2}{2\pi^2 f} \{\pi^2 \coth \alpha - 2E'K'\} - \frac{(Q_1 - Q_2)^2}{4f}.$$

It is interesting to get the results for any charges upon the cylinders directly, without making use of the line charges. This can be done by using the χ-plane shown in Fig. 11.
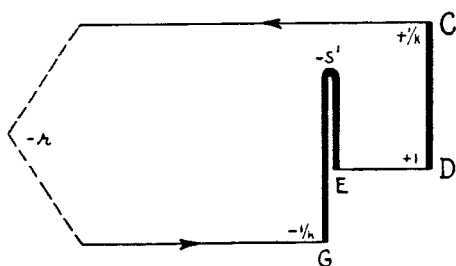
Fig. 11.

$t = -s'$ corresponds to the point on the cylinder of radius b where the surface density changes sign. We shall assume that the cylinder of radius a is at potential V and the cylinder of radius b at potential O. The transformation to the t-plane is given by

$$\frac{d\chi}{dt} = C' \frac{t + s'}{(t + r)\{t^2 - 1\cdot t^2 - 1, k^2\}^{\frac{1}{2}}}$$

with

$$C' = -\frac{2(Q_1 + Q_2)cn\,\delta\,dn\,\delta}{k\,sn\,\delta(1 - ks'\,sn\,\delta)}.$$

This is the same as equation (37) in Article 12, with $Q_1 + Q_2$ replacing $Q_a + Q_b$, and s' replacing s. But the equations for determining the constants are now different, being

$$
\begin{aligned}
t &= 1\,k, & \chi &= V + 2\pi i(Q_1 + Q_2), \\
t &= 1, & \chi &= V + 2\pi iQ_2, \\
t &= -1, & \chi &= 2\pi iQ_2, \\
t &= -1/k, & \chi &= 0.
\end{aligned}
$$

Substituting these values, we find

$$\frac{ks'}{1 - ks'\,sn\,\delta} = \frac{4(Q_1 + Q_2)KZ(\delta) + V}{4(Q_1 + Q_2)K\,cn\,\delta\,dn\,\delta},$$

an equation for determining s', and in addition we get equation (54) for determining the difference of potential between the cylinders just as when the line charges were used. The electric intensity at any point in the z-plane and the surface density on either cylinder can also be obtained by this method, the results being the same as those when the line charges were used. For the cylinder of radius a we get in this way directly the sum of (52) and (55).

16. *Two Unequal Cylinders Connected by a Conducting Sheet.*—If the two cylinders are connected by a conducting sheet, as shown in Fig. 12, we get what might be considered a two-dimensional dumb-bell. The x-plane is the same as in Article 10, and the χ-plane is shown in Fig. 13.
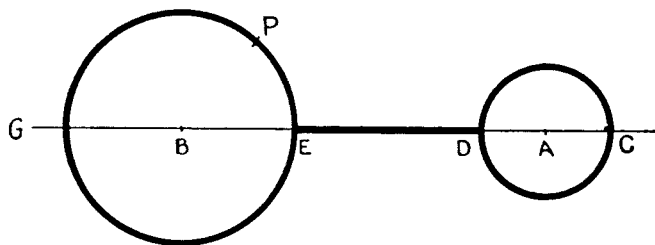
FIG. 12.
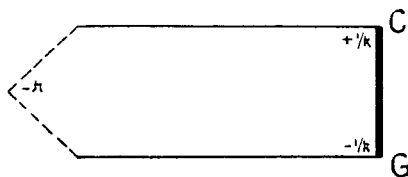
FIG. 13.

The transformation from the χ- to the t-plane is given by

$$\frac{d\chi}{dt} = \frac{C}{(t + r)\{t^2 - 1/k^2\}^{\frac{1}{2}}}.$$

where

$$C = \frac{4Q}{k} \frac{cn\ \delta}{sn\ \delta}.$$

$2Q$ is taken as the charge per unit length on the whole conductor formed of the two cylinders and the conducting sheet. The surface densities of the charge on the two cylinders are

$$\sigma_a = \frac{Qk'K'\ cn\ \delta}{\pi^2 f} \frac{cn(u', k')}{1 + sn\ \delta\ dn(u', k')}\ (\cosh \alpha - \cos u),$$

$$\sigma_b = \frac{Qk'K'\ cn\ \delta}{\pi^2 f} \frac{cn(u', k')}{1 - sn\ \delta\ dn(u', k')}\ (\cosh \beta - \cos u),$$

and the surface density on the plane sheet is

$$\sigma = \frac{QkK'}{\pi^2 f}\ cn\ \delta\ \frac{cn\ v'}{1 + k\ sn\ \delta\ sn\ v'}\ (\cosh v + 1).$$

u' and v' are the same as in (51).

The charges on the two cylinders are

$$Q_a = Q \left\{ 1 - \frac{2}{\pi} \sin^{-1} \frac{sn\ \delta + k}{1 + k\ sn\ \delta} \right\},$$

$$Q_b = Q \left\{ 1 + \frac{2}{\pi} \sin^{-1} \frac{sn\ \delta - k}{1 - k\ sn\ \delta} \right\},$$

and the charge on both sides of the conducting plane is

$$Q_p = \frac{2Q}{\pi} \left\{ \sin^{-1} \frac{sn\ \delta + k}{1 + k\ sn\ \delta} - \sin^{-1} \frac{sn\ \delta - k}{1 - k\ sn\ \delta} \right\}.$$

17. *Two Unequal Cylinders Connected by a Conducting Sheet in a Uniform Field Along the Line of Centres.*—The two cylinders and the conducting plane form a single conductor which we shall assume to be uncharged; the external field induces equal and opposite charges upon it. The z-plane to be considered is the upper half of the diagram in Fig. 12. P is the point of equilibrium, to be determined, which separates the positive and the negative induced charges. The potential of the conductor is taken as $\varphi = 0$. The χ-plane is shown in Fig. 14. The point at infinity in the z-plane
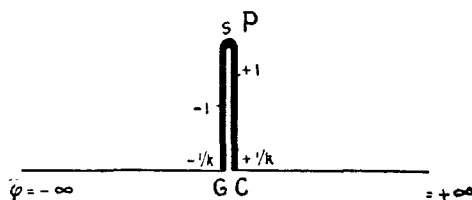
FIG. 14.

corresponds to $t = -r$ in the t-plane, where $1/r = k\ sn\ \delta$. Accordingly, we first use an auxiliary t' plane, related to the t-plane by

$$t' = \frac{1}{t + r}, \tag{56}$$

so that when $t = -r$, $t' = \infty$. The transformation from the χ- to the t'-plane is now given by

$$\frac{d\chi}{dt'} = \frac{C'\left(t' - \dfrac{1}{s+r}\right)}{\left\{t' - \dfrac{k}{1+rk}\cdot t' + \dfrac{k}{1-rk}\right\}^{\frac{1}{2}}} \cdot$$

Returning to the t-plane by (56) we have

$$\frac{d\chi}{dt} = \frac{Ck(s-t)}{(t+r)^2(1-k^2t^2)^{\frac{1}{2}}}, \tag{57}$$

where C is a new constant. Its value is to be determined from the field at infinity, F. We find

$$\frac{d\chi}{dz} = \frac{iCK'k\ sn^2\ \delta}{\pi f}$$

$$\times \frac{\left\{1 + ks\ sn\left(\dfrac{iK'w}{\pi} + \delta\right)\right\}dn\left(\dfrac{iK'w}{\pi} + \delta\right)}{\left\{sn\left(\dfrac{iK'w}{\pi} + \delta\right) - sn\ \delta\right\}^2}(1 - \cos w).$$

At infinity, $w = 0$, and evaluating the indeterminate form in this expression we get

$$C = \frac{2ifFK'\ cn^2\ \delta\ dn\ \delta}{\pi k\ sn^2\ \delta(1 + ks\ sn\ \delta)} \cdot$$

(55) is to be integrated under the conditions that $\chi = 0$ when $t = \pm\ 1/k$, and the result is

$$\chi = \frac{2ifFK'\ dn\ \delta\{1 - k^2t^2\}^{\frac{1}{2}}}{\pi(1 + kt\ sn\ \delta)}, \tag{58}$$

together with

$$ks = -\ sn\ \delta. \tag{59}$$

This equation determines s. If δ is positive, that is, if b is greater than a, s is negative and the point of equilibrium P is either on the cylinder of radius b or on the conducting plane, nearer to the larger than the smaller cylinder. If the cylinders have equal radii, $\delta = 0$, and P is at the midpoint of the plane.

(58) may be written

$$\chi = \frac{2ifFK'\ dn\ \delta}{\pi}\ \frac{dn\ \lambda}{1 + k\ sn\ \delta\ sn\ \lambda} \cdot$$

If we use the values of $dn\,\lambda$ and $sn\,\lambda$ on the two cylinders and the plane conducting sheet given by (47), (48) and (50), we find that the real part of χ vanishes on all the conductor. If, further, we let w in (35) approach o, as it does in the distant parts of the z-plane, we find that the real part of χ approaches

$$\frac{2fFv}{u^2 + v^2}.$$

From (26) we see that when u and v approach o, x approaches the value

$$\frac{2fv}{u^2 + v^2}.$$

Therefore the real part of χ approaches the value

$$\varphi = Fx$$

in the distant parts of the z-plane. So the solution we have obtained satisfies all the conditions of the problem and the use of the auxiliary t'-plane is justified.

The charges induced upon the two cylinders and the plane may be derived directly from (58) and are

$$Q_a = -\frac{FfK'k'\,dn\,\delta}{\pi^2(1 + k\,sn\,\delta)},$$

$$Q_b = \frac{FfK'k'\,dn\,\delta}{\pi^2(1 - k\,sn\,\delta)},$$

$$Q_p = -\frac{2FfK'kk'\,sn\,\delta}{\pi^2\,dn\,\delta},$$

$$Q_a + Q_b + Q_p = 0.$$

The surface densities of the induced charge on the two cylinders and the plane are

$$\sigma_a = -\frac{FK'^2k'\,dn\,\delta}{2\pi^3}$$
$$\times \frac{\{dn(u', k') + sn\,\delta\}cn(u', k')}{\{1 + sn\,\delta\,dn(u', k')\}^2}\,(\cosh\alpha - \cos u),$$

$$\sigma_b = \frac{FK'^2k'\,dn\,\delta}{2\pi^3}\frac{\{dn(u', k') - sn\,\delta\}cn(u', k')}{\{1 - sn\,\delta\,dn(u', k')\}^2}\,(\cosh\beta - \cos u),$$

$$\sigma_\mu = -\frac{F K'^2 k \, dn \, \delta \, \{k \, sn \, v' + sn \, \delta \} cn \, v'}{2\pi^3 \quad \{1 + k \, sn \, \delta \, sn \, v'\}^2} (\cosh v + 1).$$

u' and v' are the same as in (51).

18. *A Freely Charged Conductor Formed of a Plane and a Parallel Cylinder Connected by a Thin Sheet.*—From the solution in the last article we can immediately deduce that of a plane, freely charged, to which is attached by means of a thin conducting sheet a long cylinder parallel to the plane. The section of the conductor so formed is shown in Fig. 15. In
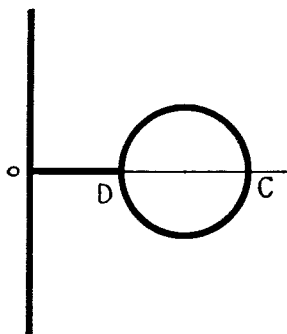
FIG. 15.

the solution of the last article, put $\delta = 0$, so that the two cylinders have equal radii. Then the plane $x = 0$ is at potential 0, the same as that of the cylinders, and can therefore be made a conducting surface. If the conductor is positively charged the surface density on the cylinder is

$$\sigma = \frac{F K'^2 k'}{2\pi^3} dn(u', k') cn(u', k')(\cosh \alpha - \cos u).$$

It is o at D, where $u = \pi$. On the conducting sheet OD the surface density is

$$\sigma = \frac{F K'^2 k^2}{2\pi^3} sn\left(\frac{K'v}{\pi}\right) cn\left(\frac{K'v}{\pi}\right) (\cosh v + 1).$$

This vanishes at both O, where $v = 0$, and at D, where $v = \alpha$. On the plane $x = 0$, the surface density is

$$\sigma = \frac{FK'^2}{2\pi^3} \frac{cn(u', k')dn(u', k')}{sn^2(u', k')} (1 - \cos u).$$

At a great distance from the cylinder when u approaches o, this tends to the value $F/4\pi$. At the point O, where $u = \pi$, the surface density vanishes.

19. *Two Unequal Cylinders in a Uniform Field Perpendicular to the Line of Centres.*—Taking $\varphi = 0$ as the potential of the cylinders, the values of φ in the upper half of the z-plane lie between o and $-\infty$. Since the point at infinity in the z-plane corresponds to $t = -r$, we again use the auxiliary t'-plane determined by (56). The χ-plane is now the t'-plane turned through a right angle. Accordingly,

$$\chi = \frac{iC}{t + r}.$$

Or, with $t = sn \lambda$,

$$\chi = \frac{iCk \, sn \, \delta}{1 + k \, sn \, \delta \, sn \, \lambda}.$$

From this we can find $d\chi/dz$, and then determine the constant C so that the field at infinity is F. The result is

$$C = \frac{2fFK'}{k\pi} \frac{cn \, \delta \, dn \, \delta}{sn^2 \, \delta}.$$

Since the plane $y = 0$ is at potential O, this problem is the same as that of a freely charged infinite plane with two unequal half-cylinders standing upon it. Figure 16 shows a sec-

G   B   E D A C

FIG. 16.

tion. The case is that of two parallel mountain ranges, each considered as having a semi-circular section perpendicular to its length.

The surface density on the cylinder of radius a is

$$\sigma_a = \frac{FK'^2 k'^2}{2\pi^3} cn\,\delta\,dn\,\delta$$
$$\times \frac{cn(u',\,k')sn(u',\,k')}{\{1 + sn\,\delta\,dn(u',\,k')\}^2}(\cosh\alpha - \cos u).\quad(60)$$

That on the cylinder of radius b is obtained by interchanging α and β, and changing the sign of $sn\,\delta$.

On the plane $u = \pi$ between the two cylinders the surface density is

$$\sigma = \frac{FK'^2 k}{2\pi^3} cn\,\delta\,dn\,\delta\,\frac{cn\,v'\,dn\,v'}{\{1 + k\,sn\,\delta\,sn\,v'\}^2}(\cosh v + 1).$$

On the plane $u = 0$, outside the cylinders, the surface density is

$$\sigma = \frac{FK'^2}{2\pi^3} cn\,\delta\,dn\,\delta\,\frac{cn\,v'\,dn\,v'}{\{sn\,\delta + sn\,v'\}^2}(\cosh v - 1).$$

When v approaches 0, at a great distance from the cylinders, this approaches the constant value $F/4\pi$.

The charge on unit length of the half cylinder of radius a is

$$Q_a = \frac{FK'f}{2\pi^2}\frac{(1 - k)cn\,\delta\,dn\,\delta}{(1 + sn\,\delta)(1 + k\,sn\,\delta)}.$$

That on the half-cylinder of radius b is

$$Q_b = \frac{FK'f}{2\pi^2}\frac{(1 - k)cn\,\delta\,dn\,\delta}{(1 - sn\,\delta)(1 - k\,sn\,\delta)}.$$

On the portion of the plane between the two cylinders the charge per unit length is

$$Q = \frac{FK'^2 f k\,cn\,\delta}{\pi^2}\frac{}{dn\,\delta}.$$

By putting $\delta = 0$, and so $sn\,\delta = 0$, $cn\,\delta = dn\,\delta = 1$, we get the case of equal cylinders.

20. *Two Unequal Insulated Cylinders in a Uniform Field Along the Line of Centres.*—In the problem of Article 17 the

two cylinders were supposed connected by a conducting sheet.
This simplified the transformation of the χ-plane to the t-
plane. We shall now suppose that the two cylinders are insu-
lated from each other; the sum of the charges upon the two
cylinders is now zero. We shall first suppose that the two
cylinders are at the same potential; then by introducing two
equal and opposite line charges at the inverse points we can
make the charge on each cylinder vanish and determine the
difference of potential in any field between the two uncharged
cylinders.

The χ-plane is shown in Fig. 17 (a, b) for the case when
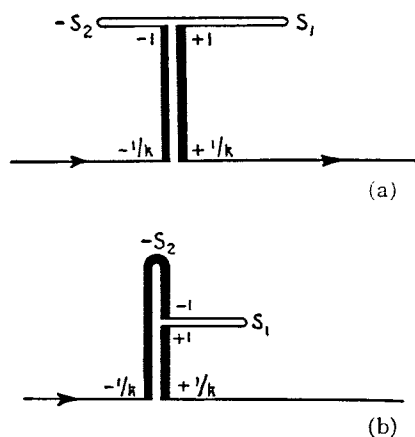
FIG. 17.

b is greater than a. Which of the two forms applies depends
upon the relative radii of the cylinders and their distance
apart. In (b) there is a point of equilibrium upon the cylinder
b and another upon the segment of the x-axis lying between
the two cylinders. In (a) there are two points of equilibrium
upon this segment of the x-axis. Both these cases are in-
cluded in the same transformation which is found just as in
Article 17. The result is

$$\frac{d\chi}{dt} = \frac{C(s_1 - t)(s_2 + t)}{(1 + nt)^2 \{1 - k^2 t^2 \cdot 1 - t^2\}^{\frac{1}{2}}}, \qquad (61)$$

where $n = 1/r = k\, sn\, \delta$.

The integral of (61) may be reduced to an algebraic part and to the three kinds of elliptic integrals. The result is

$$\frac{k^2\chi}{C} = - T \frac{sn\ \delta\ cn\ \lambda\ dn\ \lambda}{1 + k\ sn\ \delta\ sn\ \lambda}$$

$$+ R\lambda - T\left\{\frac{E}{K}\lambda + Z(\lambda)\right\} + S\Pi(\lambda, \delta, k)$$

$$+ iS\ \sin^{-1}\left\{\frac{1 - n^2}{1 - k^2}\frac{1 - k^2t^2}{1 - n^2t^2}\right\}^{\frac{1}{2}} + D, \quad (62)$$

where $t = sn\ \lambda$, and

$$T = \frac{k^2 s_1 s_2\ sn^2\ \delta - k(s_1 - s_2)sn\ \delta - 1}{cn^2\ \delta\ dn^2\ \delta},$$

$$R = \frac{k^2 s_1 s_2 - k(s_1 - s_2)sn\ \delta - 1}{cn^2\ \delta},$$

$$S = \frac{- k(s_1 - s_2)(1 - k^2\ sn^4\ \delta) + k^2 s_1 s_2\ sn\ \delta(cn^2\ \delta + dn^2\ \delta) - sn\ \delta(k^2\ cn^2\ \delta + dn^2\ \delta)}{cn^3\ \delta\ dn^3\ \delta}.$$

$\Pi(\lambda, \delta, k)$ and $Z(\lambda)$ are the Jacobian functions introduced in Article 12.

In order to determine the constants we use the scheme of Article 12 (43), except for the values of χ, and with the addition of the values of $Z(\lambda)$. So we have

$t =$	$1/k$	$+ 1$	$- 1$	$- 1/k$
$\lambda =$	$K + iK'$	$+ K$	$- K$	$- K + iK'$
$Z(\lambda) =$	$- \dfrac{i\pi}{2K}$	o	o	$- \dfrac{i\pi}{2K}$
$\chi =$	o	$2\pi iQ$	$2\pi iQ$	o

Substituting these in (62) we get

$$RK = TE,$$
$$S = o,$$

$$k(s_1 - s_2) = \frac{sn\ \delta(k'^2 K - 2E)}{E\ sn^2\ \delta + K\ cn^2\ \delta},$$

$$k^2 s_1 s_2 = \frac{K\ dn^2\ \delta - E}{E\ sn^2\ \delta + K\ cn^2\ \delta}.$$

These two equations determine the values of s_1 and s_2 which are the real values of t corresponding to the points of equilibrium. We also find

$$C = 4Qk^2(E\,sn^2\,\delta + K\,cn^2\,\delta),\qquad(63)$$

$$D = i\,\frac{\pi}{2}\,\frac{1}{E\,sn^2\,\delta + K\,cn^2\,\delta}.$$

We can now write

$$R = -\,\frac{E}{E\,sn^2\,\delta + K\,cn^2\,\delta},$$

$$T = -\,\frac{K}{E\,sn^2\,\delta + K\,cn^2\,\delta},$$

and the complex potential is given by

$$\chi = 4KQ\left\{\frac{sn\,\delta\,cn\,\lambda\,dn\,\lambda}{1 + k\,sn\,\delta\,sn\,\lambda} + Z(\lambda)\right\} + 2\pi iQ.\qquad(64)$$

21. *Electric Intensity and Surface Density.*—We find in the usual way

$$\frac{d\chi}{dz} = \frac{CK'}{\pi k^2 f}\,\frac{K\,dn^2\,\delta - E + k\,sn\,\delta(k'^2K - 2E)sn\,\lambda - (E\,sn^2\,\delta + K\,cn^2\,\delta)k^2\,sn^2\,\lambda}{(E\,sn^2\,\delta + K\,cn^2\,\delta)(1 + k\,sn\,\delta\,sn\,\lambda)^2}\,(1 - \cos w).$$

Since $\left|\dfrac{d\chi}{dz}\right| = F$ at the infinite point in the z-plane where $w = 0$, and $sn\,\lambda = -\,1/(k\,sn\,\delta)$, we have to evaluate

$$\frac{1 - \cos w}{(1 + k\,sn\,\delta\,sn\,\lambda)^2}$$

for $w = 0$. It is found that this approaches the limit

$$-\,\frac{\pi^2}{2}\,\frac{sn^2\,\delta}{K'^2\,cn^2\,\delta\,dn^2\,\delta},$$

and so we get

$$C = -\,\frac{2k^2 Ff K'}{\pi K}\,(E\,sn^2\,\delta + K\,cn^2\,\delta).$$

By (63) we get for the induced charges $\pm\,Q$,

$$Q = \frac{FK'f}{2\pi K} = \frac{Ff}{\alpha + \beta},\qquad(65)$$

where (34) has been used. We can now write

$$\frac{dx}{dz} = \frac{2FK'^2}{\pi^2 K} \frac{\begin{array}{l} K\,dn^2\,\delta - E + k\,sn\,\delta(k'^2K - 2E)sn\,\lambda \\ \quad - k^2(E\,sn^2\,\delta + K\,cn^2\,\delta)sn^2\,\lambda \end{array}}{(1 + k\,sn\,\delta\,sn\,\lambda)^2}\,(1 - \cos x).$$

To find the surface density of the distribution on the two cylinders we use the values given in (47) and get

$$\sigma_a = -\frac{FK'^2}{2\pi^3 K} \frac{\begin{array}{l} E - K\,dn^2\,\delta + (2E - k'^2K)sn\,\delta\,dn(u',k') \\ \quad + (E\,sn^2\,\delta + K\,cn^2\,\delta)dn^2(u',k') \end{array}}{\{1 + sn\,\delta\,dn\,(u',k')\}^2} \\ \times (\cosh \alpha - \cos u). \quad (66)$$

σ_b is obtained by changing the sign, writing β for α and changing the sign of $sn\,\delta$.

It can now be shown that the results in Part I for two cylinders in contact may be deduced from the results just obtained. For cylinders in contact, the modular angle becomes o, and

$$E = K = \frac{\pi}{2}, \qquad K' = \infty, \qquad k = 0, \qquad k' = 1,$$

$$dn(u, 0) = 1, \qquad sn(u, 0) = \sin u, \qquad cn(u, 0) = \cos u,$$

$$sn(u, 1) = \tanh u, \qquad cn(u, 1) = dn(u, 1) = \operatorname{sech} u.$$

By (26) on the cylinder of radius a,

$$\frac{y}{x} = \tan \theta = \frac{\sin u}{\sinh v} = \frac{\sin u}{\sinh \alpha}.$$

Since α and β approach o, u also approaches o and so we can put

$$\tan \theta = \frac{u}{\alpha}.$$

Then by (34)

$$\frac{K'u}{\pi} = u' = \frac{\pi\alpha}{\alpha + \beta}\tan \theta = \frac{\pi b}{a + b}\tan \theta$$

and

$$\cosh \alpha - \cos u = \tfrac{1}{2}(\alpha^2 + u^2) = \tfrac{1}{2}\alpha^2 \sec^2 \theta,$$

$$\sin \delta = \sin \frac{\pi}{2} \frac{b - a}{b + a} = - \cos \frac{\pi b}{a + b},$$

and we finally arrive at the result given by (20) in Part I.

22. *Insulated, Uncharged Cylinders.*—The problem whose solution we have obtained is that of two cylinders at the same potential with equal and opposite charges; Q has been taken as the charge on one of the cylinders. These conditions may be realized if, after bringing the two insulated cylinders into the uniform field, they are connected by a wire for an instant so as to bring them to the same potential. If now we place a line charge $+ Q$ at the inverse point F in the cylinder of radius a, and an equal and opposite line charge at the inverse point F' in the cylinder of radius b, the resultant charge on each cylinder will vanish, and the difference of potential between the two cylinders will be

$$V = 2Q(\alpha + \beta) = 2fF,$$

where Q is taken from (65). It therefore follows that all pairs of insulated cylinders having the same inverse points will have the same difference of potential in a given uniform field, F, along the line of centres.

The surface densities, σ_a', σ_b', to be added to (66) and to the corresponding value of σ_b are

$$\sigma_a' = \frac{FK'}{4\pi^2 K}(\cosh \alpha - \cos u),$$

$$\sigma_b' = - \frac{FK'}{4\pi^2 K}(\cosh \beta - \cos u).$$

There is now one point of equilibrium on the upper half of each cylinder.

In a uniform field perpendicular to the line of centres, the solution was given in Article 12. Since, in this case, the whole plane $y = 0$ is at zero potential it will make no difference whether a part of this plane is a conductor or not, and so the

distribution on the cylinders will be that given by (60) and the analogous expression for σ_b. It therefore follows that two uncharged insulated cylinders when brought into any uniform field will have a difference of potential

$$V = 2fF \cos \varphi,$$

where φ is the angle between the direction of the field and the line of centres of the two cylinders.

23. An alternative way of getting the results of the last article is to assume the cylinders uncharged and at a difference of potential V. The χ-plane is shown in Fig. 18; $- s'$ and s
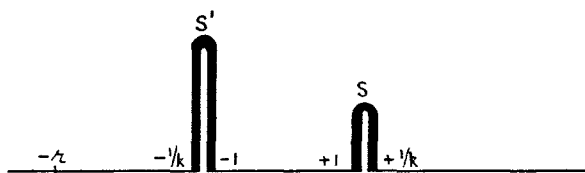
FIG. 18.

are the real values of t that correspond to the points of equilibrium on the cylinders of radius b and a respectively. They are given by the two equations

$$k(s - s') = \frac{sn\ \delta\{k'^2 K' - 2(K' - E')\}}{K' - E' sn^2\ \delta},$$

$$k^2 ss' = \frac{K'\ dn^2\ \delta - (K' - E')}{K' - E' sn^2\ \delta}.$$

The differential equation for the transformation from the χ- to the t-plane is the same as (61) with s, s' replacing s_1, s_2. The equations for determining the constants are now

$$\begin{aligned}
t &= 1/k, & \chi &= V, \\
t &= 1, & \chi &= V, \\
t &= -1, & \chi &= 0, \\
t &= -1/k, & \chi &= 0,
\end{aligned}$$

if we assume that the cylinder of radius a is at potential V and the cylinder of radius b at potential 0.

PART III

INTERSECTING CYLINDERS

24. *Transformation of the z- to the w-Plane.*—The transformation of the z-plane to the w-plane used in Part II furnishes, in addition to the circles external to each other, circles that all pass through the two inverse points. Any two circles of this family may be taken as representing a pair of intersecting cylinders. It will be convenient to take the transformation in the form

$$z = f \cot \tfrac{1}{2}w,$$

so that the x-axis is the axis of symmetry, and the inverse points lie upon the y-axis. We now have

$$
\left.
\begin{aligned}
x &= \frac{f \sin u}{\cosh v - \cos u}, \\
y &= \frac{f \sinh v}{\cosh v - \cos u}.
\end{aligned}
\right\}
\tag{67}
$$

The circles $u =$ constant have radii $f \csc u$, with their centres on the x-axis at a distance $f \cot u$ from the origin. If u is positive, the centres are on the positive x-axis. The circles $v =$ constant have radii $f \operatorname{cosech} v$, with their centres on the y-axis at a distance $f \coth v$ from the origin. If v is positive the centres lie on the negative y-axis. The upper half of the z-plane is shown in Fig. 19.
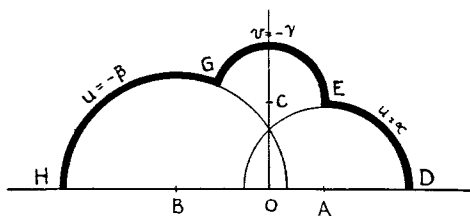
FIG. 19.

The two intersecting cylinders, with centres at A and B, are given by $u = \alpha$ and $u = -\beta$ respectively. To make the problem a little more general we shall suppose that the two

cylinders given by $v = -\gamma$, with centre at C and radius c, and $v = +\gamma$ with its centre at an equal distance below the x-axis, are included as a part of the conductor.   We now have

$$
\begin{aligned}
a &= f \csc \alpha, \\
b &= f \csc \beta, \\
c &= f \operatorname{cosech} \gamma, \\
2d &= f(\cot \alpha + \cot \beta), \\
OC &= f \coth \gamma.
\end{aligned}
\tag{68}
$$

The elements of arc of the two families of circles are

$$
\begin{aligned}
ds_u &= \frac{fdv}{\cosh v - \cos u}, \\
ds_v &= \frac{fdu}{\cosh v - \cos u}.
\end{aligned}
\tag{69}
$$

25. *The x-Plane.*—Referring to Fig. 19 it is seen that along the x-axis from $-\infty$ to H, $v = 0$ and u decreases from 0 to $-\beta$. Along the circular arc HG, $u = -\beta$ and v decreases from 0 to $-\gamma$. Along the circular arc GE, $v = -\gamma$ and u increases from $-\beta$ to $+\alpha$. Along the circular arc ED, $u = \alpha$ and v increases from $-\gamma$ to 0. Finally, along the x-axis from D to $+\infty$, $v = 0$ and u falls from α to 0. The x-plane is accordingly shown in Fig. 20. The values of t for transfor-
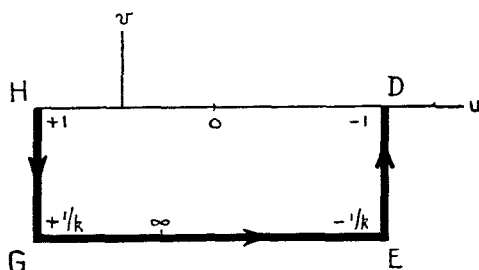
FIG. 20.

mation to the t-plane are indicated inside the rectangle. The transformation is given by the equation

$$
\frac{dw}{dt} = -\frac{Ak}{\{1 - t^2 \cdot 1 - k^2 t^2\}^{\frac{1}{2}}}
$$

just as in Article 10. Integration gives

$$x = - Ak\lambda + B,$$

where $t = sn\ \lambda$. The corresponding values are given by the scheme:

$t =$	1	$1/k$	$- 1/k$	$- 1$
$\lambda =$	K	$K + iK'$	$- K + iK'$	$- K$
$x =$	$- \beta$	$- \beta - i\gamma$	$\alpha - i\gamma$	α

We accordingly find

$$\gamma \frac{K}{K'} = \frac{\alpha + \beta}{2}, \tag{70}$$

$$Ak = \frac{\gamma}{K'},$$

$$B = \tfrac{1}{2}(\alpha - \beta),$$

so that

$$x = - \frac{\gamma}{K'}\lambda + \tfrac{1}{2}(\alpha - \beta),$$

which may be written

$$\lambda = - \frac{2Kx}{\alpha + \beta} + \delta \tag{71}$$

with

$$\delta = K\frac{\alpha - \beta}{\alpha + \beta}. \tag{72}$$

The point at infinity in the z-plane, where $x = 0$, corresponds to

$$\lambda = \delta, \quad \text{or} \quad t = sn\ \delta.$$

When $t = \infty$, $\lambda = iK'$, and

$$x = - i\gamma + \tfrac{1}{2}(\alpha - \beta).$$

This point therefore lies upon the cylinder of radius c. When $t = 0$,

$$x = \tfrac{1}{2}(\alpha - \beta).$$

The values of the elliptic functions that are needed on the three cylinders are given for reference:

$$\lambda_a = - K - iv',$$

$$sn\ \lambda_a = - \frac{1}{dn(v', k')},$$

$$cn\ \lambda_a = - ik'\frac{sn(v', k')}{dn(v', k')},$$

$$dn\ \lambda_a = k'\frac{cn(v', k')}{dn(v', k')},$$

$$\tag{73}$$

$$\left.\begin{aligned}
\lambda_b &= K - iv',\\
sn\ \lambda_b &= - sn\ \lambda_a,\\
cn\ \lambda_b &= - cn\ \lambda_a,\\
dn\ \lambda_b &= dn\ \lambda_a,
\end{aligned}\right\} \tag{74}$$

$$\lambda_c = - u' - iK',$$

$$sn\ \lambda_c = - \frac{1}{k}\frac{1}{sn\ u'},$$

$$cn\ \lambda_c = - \frac{i}{k}\frac{dn\ u'}{sn\ u'},$$

$$dn\ \lambda_c = - i\frac{cn\ u'}{sn\ u'}.$$

$$\tag{75}$$

u' and v' are given by

$$\left.\begin{aligned}
u' &= \frac{2Ku}{\alpha + \beta} - \delta,\\
v' &= \frac{2Kv}{\alpha + \beta}.
\end{aligned}\right\} \tag{76}$$

26. *The χ-Plane.*—The potential of the conductor is taken as $\varphi = 0$. The χ-plane for the freely charged conductor is shown in Fig. 21, and the transformation to the t-plane is
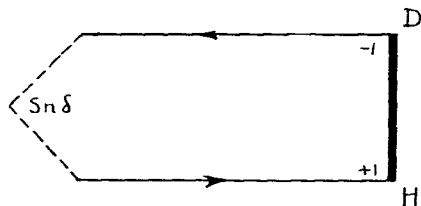
FIG. 21.

given by

$$\frac{d\chi}{dt} = \frac{C}{(t - sn\ \delta)(t^2 - 1)^{\frac{1}{2}}}.$$

If $2Q$ is the charge on unit length of the conductor formed of the outer surfaces of the four cylinders, χ decreases by $4\pi iQ$ when t passes through $sn\ \delta$ on the real t-axis. So we have

$$C = 4iQ\ cn\ \delta,$$

and we find

$$\chi = 4iQ\ \sin^{-1}\frac{t\ sn\ \delta - 1}{t - sn\ \delta} + 2\pi iQ. \tag{77}$$

This solution satisfies the conditions that $\chi = 0$ for $t = +1$ and $\chi = 4\pi iQ$ for $t = -1$.

From the differences of the values of ψ at the points D, E, G and H we find the charges on the cylinders. They are

$$Q_a = Q\left\{1 - \frac{2}{\pi}\sin^{-1}\frac{sn\ \delta + k}{1 + k\ sn\ \delta}\right\},$$

$$Q_b = Q\left\{1 + \frac{2}{\pi}\sin^{-1}\frac{sn\ \delta - k}{1 - k\ sn\ \delta}\right\},$$

$$Q_c = \frac{2Q}{\pi}\left\{\sin^{-1}\frac{sn\ \delta + k}{1 + k\ sn\ \delta} - \sin^{-1}\frac{sn\ \delta - k}{1 - k\ sn\ \delta}\right\}.$$

If the cylinders of radius c are not present the modular angle is equal to zero, and so $k = 0$, and the two corners G, E of the rectangle in the w-plane go off to infinity. The elliptic functions degenerate into circular and hyperbolic functions. Thus $sn\ \delta$ becomes $\sin\ \delta$, and we get

$$Q_a = \frac{2Q\beta}{\alpha + \beta},$$

$$Q_b = \frac{2Q\alpha}{\alpha + \beta},$$

and so

$$\frac{Q_a}{Q_b} = \frac{\beta}{\alpha} \tag{78}$$

and this is also

$$\frac{Q_a}{Q_b} = \frac{\text{Angle } FHO}{\text{Angle } FDO}.$$

For the two cylinders in contact, α, β and f approach zero in such a way that $a = f_{,}'\alpha$, $b = f_{,}'\beta$, and so we get

$$Q_a\,'Q_b = a_{,}'b$$

as was found in Part I, Article 2.

27. *Electric Intensity and Surface Density.*—From the relation

$$\frac{d\chi}{dz} = \frac{d\chi}{dt}\frac{dt}{dx}\frac{dx}{dz}$$

we find

$$\frac{d\chi}{dz} = \frac{4K'Q\,cn\,\delta}{f\gamma}\,\frac{dn\,\lambda}{sn\,\lambda - sn\,\delta}\,(1 - \cos x).$$

Using the values given in Article 25 we can express the surface density of the charges on the cylinders.   These are

$$\sigma_a = \frac{2Kk'Q\,cn\,\delta}{\pi f(\alpha + \beta)}\,\frac{cn(v',\,k')}{1 + sn\,\delta\,dn(v',\,k')}\,(\cosh v - \cos \alpha).$$

σ_b is obtained from σ_a by changing the sign of $sn\,\delta$ and writing β for α.

$$\sigma_c = \frac{2KkQ\,cn\,\delta}{\pi f(\alpha + \beta)}\,\frac{cn\,u'}{1 + k\,sn\,\delta\,sn\,u'}\,(\cosh \gamma - \cos u).$$

u' and v' are given in (76).

If the cylinders of radius c are not present, we have $k = 0$, $k' = 1$, $K = \pi/2$, $cn\,\delta = \cos\delta$, $sn\,\delta = \sin\delta$,

$$cn(x, k') = dn(x, k') = \operatorname{sech} x, \qquad sn(x, k') = \tanh x.$$

We can also write

$$\sin \delta = \cos \frac{\pi\beta}{\alpha + \beta} = -\cos\frac{\pi\alpha}{\alpha + \beta},$$

$$\cos \delta = \sin \frac{\pi\beta}{\alpha + \beta} = \sin\frac{\pi\alpha}{\alpha + \beta},$$

and we get, when we have only the two intersecting cylinders,

$$\sigma_a = \frac{Q}{f(\alpha + \beta)}\,\frac{\sin\dfrac{\pi\alpha}{\alpha + \beta}}{\cosh\dfrac{\pi v'}{\alpha + \beta} - \cos\dfrac{\pi\alpha}{\alpha + \beta}}\,(\cosh v - \cos \alpha).$$

We can pass to the case of the two cylinders in contact if we note that α, β, v, f all approach zero. By (67)

$$\tan \theta = y'x = v'\alpha,$$

where θ is the angle the radius vector from the origin at the point of contact makes with the x-axis. So we put

$$\cosh v - \cos \alpha = \tfrac{1}{2}(v^2 + \alpha^2) = \tfrac{1}{2}\alpha^2 \tan^2 \theta$$

and, with $a = f'\alpha$, $b = f'\beta$, we get the same value for the cylinders in contact that was found in Part I (16).

28. *Intersecting Cylinders in a Uniform Field Along the Line of Centres.*—When the conductor formed of the four intersecting cylinders is placed in a uniform field the direction of which is along the line of centres of the cylinders of radius a and b, the χ-plane is shown in Fig. 22. In order to trans-
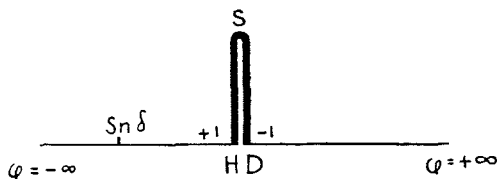
FIG. 22.

form from the χ-plane to the t-plane, we use the auxiliary t'-plane, given by

$$t' = \frac{1}{t - sn\,\delta},$$

so that, when $t = sn\,\delta$, the point at infinity in the s-plane, $t' = \infty$. Just as in previous cases, the transformation to the t-plane is given by

$$\frac{d\chi}{dt} = -C \frac{cn\,\delta}{(s - sn\,\delta)(t - sn\,\delta)^2} \frac{s - t}{(1 - t^2)^{\frac{1}{2}}}.$$

To determine the constant C, we have the condition that the electric intensity at infinity is equal to F. By the same

method as was used in previous cases, we find

$$C = \frac{4KFf \, cn \, \delta \, dn \, \delta}{(\alpha + \beta)}.$$

We can now integrate, subject to the conditions that $\chi = 0$ when $t = \pm 1$, and get

$$\chi = \frac{4KFf \, dn \, \delta \, cn \, \lambda}{(\alpha + \beta)(sn \, \lambda - sn \, \delta)}.$$

The point of equilibrium, $t = s$, is given by

$$s = \frac{1}{sn \, \delta}.$$

If the cylinders of radius c are not present, we get from

$$\sin \lambda = 1/\sin \delta,$$
$$u = -\beta,$$

showing that the point of equilibrium lies on the cylinder of radius b which we have supposed is greater than a. The position of the point of equilibrium on this cylinder is given by

$$\cosh \frac{\pi v}{\alpha + \beta} = \sec \frac{\pi \beta}{\alpha + \beta}.$$

If the two cylinders are in contact the last equation will be found to reduce to (21) of Part I.

The values of the surface density on the cylinders are:

$$\sigma_a = - \frac{2K^2Fk' \, dn \, \delta}{\pi(\alpha + \beta)^2} \frac{\{sn \, \delta + dn(v', k')\}\{cn(v', k')\}}{\{1 + sn \, \delta \, dn(v', k')\}^2}$$
$$\times (\cosh v - \cos \alpha).$$

We get σ_b by changing the sign of $sn \, \delta$ and replacing α by β.

$$\sigma_c = - \frac{2K^2Fk \, dn \, \delta}{\pi(\alpha + \beta)^2} \frac{\{sn \, \delta + k \, sn \, u'\}cn \, u'}{\{1 + k \, sn \, u'\}^2}$$
$$\times (\cosh \gamma - \cos u). \quad (80)$$

In the absence of the cylinders of radius c,

$$\sigma_a = \frac{-\pi F}{2(\alpha + \beta)^2} \frac{\left\{ 1 + \sin \delta \cosh \dfrac{\pi v}{\alpha + \beta} \right\} (\cosh v - \cos \alpha)}{\left\{ \sin \delta + \cosh \dfrac{\pi v}{\alpha + \beta} \right\}^2}$$

and its value for the two cylinders in contact given in (20) of Part I can easily be obtained from this expression.

29. *A Freely Charged Plane with a Mound in the Form of the Intersecting Cylinders.*—If $\alpha = \beta$ the plane $x = 0$ is at potential zero, and so we have obtained the solution for a freely charged plane with a mound shown in section in Fig. 23.

FIG. 23.
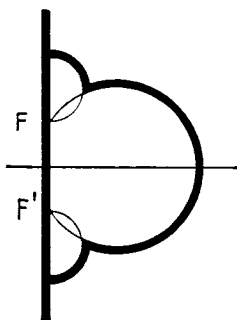
The surface densities on the cylinders are given by (79) and (80) after putting $\alpha = \beta$. On the plane $x = 0$ we have, if $\alpha = \beta$,

$$\lambda = -i \frac{Kv}{\alpha}$$

and the surface density on this plane is

$$\sigma = \frac{K^2 F}{2\pi\alpha^2} \frac{dn\left(\dfrac{Kv}{\alpha}, k'\right) cn\left(\dfrac{Kv}{\alpha}, k'\right)}{sn^2\left(\dfrac{Kv}{\alpha}, k'\right)} (\cosh v - 1).$$

When v approaches 0, at an infinite distance from the cylinders, the surface density becomes $F/4\pi$.

If the cylinders of radius c are not present the mound has the form of a segment of a cylinder lying between a full cylinder and half a cylinder. The values of the surface densities may be expressed by using the degenerate forms of the elliptic functions given in Article 27.

30. *Intersecting Cylinders in a Uniform Field Perpendicular to the Line of Centres.*—We again begin by assuming the presence of the two cylinders of radius c the line of centres of which is along the direction of the external field. The χ-plane is now simply the t'-plane turned through a right angle; so we have

$$\chi = \frac{iC}{sn\,\lambda - sn\,\delta}.$$

From this we get

$$\frac{d\chi}{dz} = -\frac{2iKC\,cn\,\lambda\,dn\,\lambda}{f(\alpha + \beta)(sn\,\lambda - sn\,\delta)^2}(1 - \cos w),$$

where the constant C, determined from the intensity at infinity, is

$$C = \frac{4Ff\,cn\,\delta\,dn\,\delta\,K}{\alpha + \beta}.$$

The surface densities are

$$\sigma_a = -\frac{2FK^2k'^2}{\pi(\alpha + \beta)^2}cn\,\delta\,dn\,\delta\,\frac{sn(v', k')cn(v', k')}{\{1 + sn\,\delta\,dn(v', k')\}^2}$$
$$\times (\cosh v - \cos \alpha).$$

σ_b is obtained by changing the sign of δ and putting β for α.

$$\sigma_c = -\frac{2FK^2k}{\pi(\alpha + \beta)^2}cn\,\delta\,dn\,\delta\,\frac{cn\,u'\,dn\,u'}{\{1 + k\,sn\,\delta\,sn\,u'\}^2}$$
$$\times (\cosh \gamma - \cos u).$$

u' and v' are given by (76).

The charges induced on the upper half of the conductor, and the equal negative charges induced on the lower half may be determined by integration of these expressions, or, more simply, from the differences of the values of ψ at the four

points H, G, E and D.   We find

$$Q_a = - \frac{KFf \, cn \, \delta \, dn \, \delta(1 - k)}{\pi(\alpha + \beta)(1 + k \, sn \, \delta)(1 + sn \, \delta)},$$

$$Q_b = - \frac{KFf \, cn \, \delta \, dn \, \delta(1 - k)}{\pi(\alpha + \beta)(1 - k \, sn \, \delta)(1 - sn \, \delta)},$$

$$Q_c = - \frac{2KFfk \, cn \, \delta}{\pi(\alpha + \beta)dn \, \delta},$$

$$Q_a + Q_b + Q_c = - \frac{2KFf \, dn \, \delta}{\pi(\alpha + \beta)cn \, \delta}.$$

This same solution applies to a freely charged infinite plane upon which a mound stands, shown in section in Fig. 24.
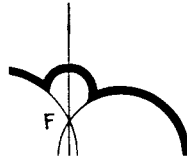
FIG. 24.

On the plane $y = 0$,

$$\lambda = \delta - \frac{2Ku}{\alpha + \beta}$$

and the surface density of the charge on this plane is

$$\sigma = \frac{2FK^2}{\pi(\alpha + \beta)^2} cn \, \delta \, dn \, \delta \, \frac{cn \, u' \, dn \, u'}{\{sn \, \delta + sn \, u'\}^2}(1 - \cos u).$$

At $u = 0$ this becomes $F/4\pi$, and it vanishes at $u = -\beta$ and at $u = \alpha$ where the mound meets the plane. The cylinder of radius c may be removed by using the degenerate forms of the elliptic functions for $k = 0$; the limiting case of the two cylinders in contact may be obtained in the same way as in previous cases and the results of Part I again obtained.

    It is worth noting that the solutions obtained in Article 24 and the following articles apply equally well to a conductor the section of which is shown in Fig. 25. This is a circle of radius b with a bulge formed of a circular arc of radius $a < b$.
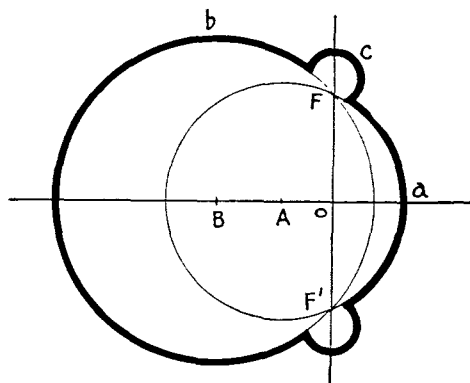
FIG. 25.

The two cylinders of radius c surrounding the inverse points may also be included in the conductor. Although in this case the centres of the circles of radius a and b are on the same side of the y-axis, the values of v corresponding to them are of opposite signs because the line connecting the inverse points subtends angles of opposite signs on the two circles. By removing the circles of radius c and letting $a = b$ we get from the solution in Article 27,

$$\sigma = \frac{Q}{\pi a},$$

the surface density on a freely charged cylinder with a charge $2Q$ per unit length.

31. *Three Unequal Intersecting Cylinders.*—A special case is that of three unequal cylinders shown in section in Fig. 26.
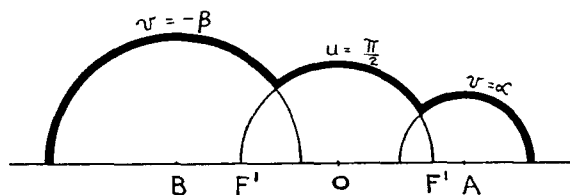
FIG. 26.

It is convenient to take in this case the transformation of the z- to the w-plane that was used in Part II. For the middle

cylinder, $u = \pi/2$, and $c = f$. On the outer cylinders of radii a and b, $v = \alpha$ and $-\beta$ respectively. For the freely charged conductor, with a charge Q per unit length, the charges on the three cylinders are, per unit length,

$$\left. \begin{aligned}
Q_a &= \frac{1}{2}Q\left\{ 1 - \frac{2}{\pi}\sin^{-1}\frac{sn\,\delta + k}{1 + k\,sn\,\delta} \right\}, \\
Q_b &= \frac{1}{2}Q\left\{ 1 + \frac{2}{\pi}\sin^{-1}\frac{sn\,\delta - k}{1 - k\,sn\,\delta} \right\}, \\
Q_c &= \frac{1}{\pi}Q\left\{ \sin^{-1}\frac{sn\,\delta + k}{1 + k\,sn\,\delta} - \sin^{-1}\frac{sn\,\delta - k}{1 - k\,sn\,\delta} \right\}.
\end{aligned} \right\} \quad (81)$$

In particular, if $a = b$,

$$Q_a = Q_b = \frac{Q}{2}\left(1 - \frac{2\theta}{\pi}\right), \qquad Q_c = \frac{2Q\theta}{\pi},$$

where θ is the modular angle. The charges on the three cylinders will be equal if $\theta = 30°$. In this case we find

$$c/a = 1.56076.$$

The surface densities on the conductor are

$$\sigma_a = \frac{QKk'\,cn\,\delta}{\pi f(\alpha + \beta)}\frac{cn(u', k')}{1 + sn\,\delta\,dn(u', k')}(\cosh\alpha - \cos u).$$

σ_b is obtained by changing the sign of δ and writing β for α.

$$\sigma_c = \frac{QKk\,cn\,\delta}{\pi f(\alpha + \beta)}\frac{cn\,v'}{1 + k\,sn\,\delta\,sn\,v'}\cosh v.$$

When the conductor is placed in an electric field along the line of centres the charges induced on the three cylinders are

$$Q_a = -\frac{2Ff K'^2(\alpha + \beta)}{K\pi^3}\frac{k'\,dn\,\delta}{1 + k\,sn\,\delta},$$

$$Q_b = \frac{2Ff K'^2(\alpha + \beta)}{K\pi^3}\frac{k'\,dn\,\delta}{1 - k\,sn\,\delta},$$

$$Q_c = -\frac{4Ff K'^2(\alpha + \beta)}{K\pi^3}\frac{kk'\,sn\,\delta}{dn\,\delta},$$

so that

$$Q_a + Q_b + Q_c = 0.$$

The surface densities are

$$\sigma_a = -\frac{2FK'^2k'\,dn\,\delta}{\pi^3}$$
$$\times \frac{cn(u', k')\{sn\,\delta + dn(u', k')\}(\cosh\alpha - \cos u)}{\{1 + sn\,\delta\,dn(u', k')\}^2},$$

$$\sigma_c = -\frac{2FK'^2k\,dn\,\delta}{\pi^3}\frac{cn\,v'\{sn\,\delta + k\,sn\,v'\}}{\{1 + k\,sn\,\delta\,sn\,v'\}^2}\cosh v,$$

where

$$u' = \frac{2K'u}{\pi}, \qquad v' = \frac{2K'v}{\pi} - \delta. \tag{82}$$

If $k = sn\,\delta$ it will be found that the point of equilibrium on the cylinder of radius b coincides with the point of equilibrium at E so that the surface density is positive everywhere on the cylinder of radius b and negative on the cylinders of radii a and c. This assumes that $b > a$ and that the field s in the direction of the negative x-axis.

In a field along the negative y-axis the charges induced on the upper halves of the cylinders are

$$Q_a = -\frac{FfK'(1 - k)}{\pi^2}\frac{cn\,\delta\,dn\,\delta}{(1 + sn\,\delta)(1 + k\,sn\,\delta)},$$

$$Q_b = -\frac{FfK'(1 - k)}{\pi^2}\frac{cn\,\delta\,dn\,\delta}{(1 - sn\,\delta)(1 - k\,sn\,\delta)},$$

$$Q_c = -\frac{2Ffk}{\pi^2}\frac{cn\,\delta}{dn\,\delta},$$

and the surface densities are

$$\sigma_a = -\frac{2FK'^2k'^2}{\pi^3}\frac{cn(u', k')sn(u', k')}{\{1 + sn\,\delta\,dn(u', k')\}^2}(\cosh\alpha - \cos u),$$

$$\sigma_c = -\frac{2FK'^2k}{\pi^3}\frac{cn\,v'\,dn\,v'}{\{1 + k\,sn\,\delta\,sn\,v'\}^2}\cosh v,$$

where u' and v' are given by (82).

32. *Two Pairs of Cylinders in Contact.*—Another interest-
ing type of intersecting cylinders is that shown in section in
Fig. 27. We have four circles: the two of unequal radii are
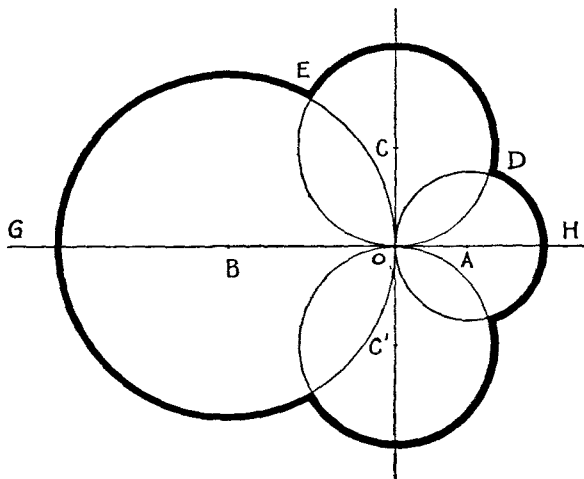
Fig. 27.

tangent to the *y*-axis at the origin, and the two of equal radii,
c, are tangent to the *x*-axis at the origin. This problem is
a generalization of the one considered in Part I, and we use
the transformation $w = 2i\sqrt{z}$ that was used there. The rela-
tions between the dimensions of the cylinders and the com-
plete elliptic integrals, K and K', are now

$$\left.\begin{array}{c} \dfrac{K}{K'} = \dfrac{c(a+b)}{2ab}, \\[2mm] \delta = K\dfrac{b-a}{b+a}. \end{array}\right\} \qquad (83)$$

If definite values of k, the modulus, and δ are assumed, so that
K and K' are known, the ratios of the radii of the cylinders
are

$$\frac{a}{c} = \frac{K'}{K+\delta},$$

$$\frac{b}{c} = \frac{K'}{K-\delta}.$$

A charge Q on unit length of the freely charged conductor divides among the four cylinders so that the charges are given by the same expressions as in (81), but with δ now defined by (83).

The surface densities are

$$\sigma_a = \frac{QbKk'\, cn\,\delta}{2\pi a(a+b)\cos^2\theta}\, \frac{cn(u',\,k')}{1 + sn\,\delta\, dn(u',\,k')}.$$

σ_b is obtained by interchanging a and b and reversing the sign of $sn\,\delta$.

$$\sigma_c = \frac{QabKk\, cn\,\delta}{2\pi c^2(a+b)\cos^2\theta}\, \frac{cn\,v'}{1 + k\, sn\,\delta\, sn\,v'}.$$

u' and v' are defined by

$$\left.\begin{aligned}
u' &= \frac{2Kb\tan\theta}{a+b}, \\[2mm]
v' &= \frac{2Kab\tan\theta}{c(a+b)} - \delta.
\end{aligned}\right\} \tag{84}$$

θ is now the angle that the radius vector from the origin makes with the x-axis in σ_a, with the $-x$-axis in σ_b, and with the y-axis in σ_c.

If $a = b = c$ we get

$$\sigma = \frac{QKk}{4\pi a}\sec^2\theta\, cn(K\tan\theta).$$

In this case $K = K'$, $k = k'$, and the modular angle is $45°$.

When placed in a uniform electric field along the negative x-axis the charges induced on the cylinders are

$$Q_a = -\frac{2FKab}{\pi(a+b)}\, \frac{k'\, dn\,\delta}{1 + k\, sn\,\delta},$$

$$Q_b = \frac{2FKab}{\pi(a+b)}\, \frac{k'\, dn\,\delta}{1 - k\, sn\,\delta},$$

$$Q_c = -\frac{2FKab}{\pi(a+b)}\, \frac{kk'\, sn\,\delta}{dn\,\delta},$$

$$Q_a + Q_b + 2Q_c = 0.$$

The surface densities are

$$\sigma_a = - \frac{Fb^2K^2k' \, dn \, \delta}{\pi(a+b)^2 \cos^2 \theta} \frac{cn(u', k')\{sn \, \delta + dn(u', k')\}}{\{1 + sn \, \delta \, dn(u', k')\}^2}.$$

σ_b is obtained from σ_a by interchanging a and b, changing the sign and reversing the sign of $sn \, \delta$. In σ_b, θ is measured from the point G.

$$\sigma_c = - \frac{Fa^2b^2K^2k \, dn \, \delta}{\pi c^2(a+b)^2 \cos^2 \theta} \frac{cn \, v'\{sn \, \delta + k \, sn \, v'\}}{\{1 + k \, sn \, \delta \, sn \, v'\}^2}.$$

When placed in an electric field along the negative y-axis the charges induced on half the cylinders are

$$Q_a = - \frac{FabK(1 - k)cn \, \delta \, dn \, \delta}{\pi(a+b)(1 + sn \, \delta)(1 + k \, sn \, \delta)},$$

$$Q_b = - \frac{FabK(1 - k)cn \, \delta \, dn \, \delta}{\pi(a+b)(1 - sn \, \delta)(1 - k \, sn \, \delta)},$$

$$Q_c = - \frac{2FabkK \, cn \, \delta}{\pi(a+b)dn \, \delta},$$

and the surface densities are

$$\sigma_a = - \frac{Fb^2K^2k'^2 \, cn \, \delta \, dn \, \delta}{\pi(a+b)^2 \cos^2 \theta} \frac{sn(u', k')cn(u', k')}{\{1 + sn \, \delta \, dn(u', k')\}^2},$$

$$\sigma_c = - \frac{Fa^2b^2K^2k \, cn \, \delta \, dn \, \delta}{\pi(a+b)^2c^2 \cos^2 \theta} \frac{dn \, v' \, cn \, v'}{\{1 + k \, sn \, \delta \, sn \, v'\}^2}.$$

In these formulae u' and v' are given by (84).

PROPOSED REFORMS OF THE GREGORIAN CALENDAR

ARTHUR E. KENNELLY

(Read April 18, 1935)

PURPOSE AND SCOPE

IT IS proposed to present here an outline of the history of the Gregorian Calendar from the days of ancient Rome to the present time, to indicate the existing defects that have been recognised in this Calendar, and the principal proposals that have been suggested for reforming it, as based upon the reports of the Committee of the League of Nations, which has had the matter under consideration during the last ten years, also to indicate therefrom the reforms that may be feasible immediately.

DEFINITIONS

A calendar, as we here use the term, is a chronological tabulation system for maintaining the historical sequence of successive days with respect to the annual changes in the positions of the sun and/or moon as well as to the established relations of clock time, so that any event, either in the recorded past, or in the expected future, may be assigned its appropriate place in the system.

An almanac is a calendar tabulation for a single year.

Many calendars have been maintained in different countries at different historical periods, such as the Arabian, Chinese, French Republican, and Hebrew calendars. Some of these are still in recognised existence, but the calendar which receives attention here is that which has come to be maintained by the civilised world today, and is known as the Gregorian Calendar.

Every calendar of precision comprises two portions:

1. An astronomical portion, based on astronomical observations and not subject to human modifications or control. Historically, calendars have been

(a) *Lunar*, or based upon the synodical month; *i.e.*, the interval between new moons. Only a very few existing calendars are lunar.

(b) *Solar*, or based on the number of mean solar days in a tropical year (interval between two successive vernal equinoxes). At a vernal equinox, the sun appears to cross the celestial equator from south to north. The Gregorian calendar is solar, with lunar vestiges (months).

(c) *Luni-solar*, or designed to conform to both lunar and solar periods. The Christian church calendar is luni-solar.

2. A conventional portion, based upon tradition, custom, or agreement, such as the number and names of the months, or of the days in the week. These conventional elements are susceptible of modification by international agreement.

The reform proposed in the Church Calendar relates both to astronomical and conventional portions.

The reforms proposed in the existing Gregorian Calendar relate to conventional elements only.

OUTLINE HISTORY OF OUR PRESENT GREGORIAN CALENDAR

Historically, our modern calendar is derived from the calendar of ancient Rome, as modified by Julius Cæsar (46 B.C.), Augustus Cæsar (8 B.C.), and Pope Gregory XIII (A.D. 1582).

The Roman calendar was luni-solar in design. It aimed to have the months follow the observed changes in the moon, and the year follow the seasons provided by the sun. The appalling task of reconciling the lunar and solar periods into the almanac for each year was left to the college of pontiffs (pontifices) at Rome. They were appointed for life, and their senior member, the pontifex maximus, announced the dates, ceremonies and festivals of the year. It was known that the mean lunar month, from new moon to new moon, was close to 29½ days;[1] so that alternate months of 29 and 30

[1] The mean Synodical month is now taken as 29.5305881 mean solar days, in A.D. 1900, and very slowly diminishing (about 1 second in 4000 years, Bibliography 17).

days would keep pace, on the average, with every second new moon. Twelve such alternating months would make a year of 354 days which would be about 11 days short of a seasonal solar year. In order to rectify the year, an extra brief month of 11 days would have to be intercalated at or near the end of the year, or a 22-day month every two years. Such a thirteenth or intercalary month of flexible number of days was a common occurrence in the almanac of ancient Rome, under the name of Mercedonius. It was the recognised purpose of the pontiffs to keep the vernal equinox, or passage of the sun across the equator from south to north, on March 25th. This could be brought about on the average with the aid of Mercedonius, but not every year.

Although it is believed that the alternation of 29- and 30-day months existed at one period in the Roman calendar it gave place to the following arrangement which was theoretically in force up to the date of Julius Cæsar's dictatorship.

TABLE I

FLAVIAN CALENDAR

Month Number	Name of Month		Days in Month
	Latin	English	
1	Martius	March	31
2	Aprilis	April	29
3	Maius	May	31
4	Junius	June	29
5	Quintilis	July	31
6	Sextilis	August	29
7	September	September	29
8	October	October	31
9	November	November	29
10	December	December	29
11	Januarius	January	29
12	Februarius	February	28
			355
13	Mercedonius Every second year	—	22 or 23
			377 or 378

Non-perpetual calendar used in Republican Rome, from about 300 B.C. up to Julius Cæsar's reform in 46 B.C. Luni-solar. Twelve and thirteen months alternately. Subject to variation and adjustment at pontifical will. No weekdays.

The above thirteen-month calendar, sometimes attri-
buted to Flavius, is supposed to have been introduced about
300 B.C. A Flavian cycle of four years had 355, 378, 355
and 377 days, giving an average of 366¼ days, or one day in
excess of the seasonal year.

It may be noted that all the regular months, except
February, have an odd number of days (29 or 31). This is
attributed to the unpopularity of even numbers in Rome
during that period. Odd numbers were regarded as more
fortunate than even numbers. Even the length of the com-
mon year was changed, it appears, from 354 to 355 days,
thus throwing it out of conformity with 12 lunations. Some
writers consider that February was allowed to keep an even
number of days, partly because it came at the end of the list,
and partly because it was devoted to the Infernal Gods, and
so was exempt from good fortune.

The intercalary month was inserted during alternate
years, not at the end of February, but between the 24th and
25th of that month; so that the year always ended with the
last days of February.

It is evident that the Roman calendar, up to the time of
Julius Cæsar, was irregular and indefinite. Historians have
difficulty in assigning dates to the changes it underwent be-
tween 500 B.C. and 50 B.C. The account here given must be
taken with reserve, owing to incomplete historical agreement.

THE JULIAN CALENDAR

The great leader Gaius Julius Cæsar (102–44 B.C.) was
elected to the college of pontiffs when he was about 30 years
of age. In 63 B.C. he was elected pontifex maximus, a posi-
tion he held for the rest of his life. He was thus faced officially
with the complexities of the Roman calendar. By that time
the almanac had drifted more than two months out of step
with and ahead of the seasons. The summer months of the
calendar were meeting with the spring season, and the winter
calendar months with the autumn season. During his
military visit to Egypt (48 B.C.), Cæsar must have come into

contact with the Egyptian calendar, which although also
luni-solar, was simpler and more permanent than that of
Rome. He seems to have decided at that time to reform the
Roman calendar. As soon as he was elected dictator in 46
B.C. he set to work upon the reform, aided by the Egyptian
astronomer Sosigenes of Alexandria, Egypt. He aimed to
restore the vernal equinox or opening of Spring, to the 25th
of March, also to make the new calendar entirely solar, and
perpetual, *i.e.* without the intercalary month of Mercedonius.
Having ascertained that the best available astronomical
estimate of the seasonal year was 365¼ days, he ordained
that despite popular superstition, the twelve months of the
year should have alternately odd and even numbers, except
February, which should have 29 days in common years and
30 days every fourth year. This would make the average
year length 365¼ days, as is seen in Table II. All years were

<div align="center">TABLE II</div>
<div align="center">JULIAN CALENDAR</div>

Month Number	Name of Month		Days in Month	Days in Quarter	Days in Half Year
	Latin	English			
1	Januarius	January	31		
2	Februarius	February	29 or 30		
3	Martius	March	31	91 or 92	
4	Aprilis	April	30		
5	Maius	May	31		
6	Junius	June	30	91	182 or 183
7	Julius	July	31		
8	Sextilis	August	30		
9	September	September	31	92	
10	October	October	30		
11	November	November	31		
12	December	December	30	91	183
			365 or 366		365 or 366

Perpetual and solar calendar set in action by the Dictator Julius Cæsar, January
1st, A.U.C. 709 or 45 B.C. Twelve months, no weeks. Fixed year of 365 days. A
supplementary day inserted every fourth year, without sequential name, between
24th and 25th February, making average length of year 365¼ days.

to commence on the first day of January. In this way, the attempt to conform with the phases of the moon would be abandoned, and the calendar should automatically keep pace with the solar seasons indefinitely.

To rectify the vernal equinox, Cæsar inserted into the year 46 B.C., not only Mercedonius, but also two new and special extra months, bringing the total length of that year to 15 months and to 445 days. It was called the "year of confusion." January 1st, 45 B.C., or 709 A.U.C., launched the first year of the new calendar. There happened also to be a new moon on that date, which was hailed as an auspicious event.

The Julian calendar was a vast improvement over the preceding fluctuating Roman almanacs, that used to vary unpredictably from year to year. The Julian half years varied only between 182 and 183 days, in common years, while in leap years they were equal. The quarters varied only between 91 and 92 days. Except for common Februarys, the months were all either 30 or 31 days. It was easy to remember which was which, because the odd months— January, March, May, etc.—had all odd-numbers of days (31); while the even months—February, April, etc.— had an even number of days (30), except February in common years. Common years had always 365 days and leap years 366. The extra day of leap year was inserted between the 24th and 25th of February, where Mercedonius had beem employed and not at the end of February as at present. In the calendar of Cæsar's time, there were neither weeks nor weekdays, and days were designated by their positions in their respective months. What we call February 25th (when common Februarys had 29 days) was called by the Romans *sextilis* (sixth) before the Calends of March (March 1st inclusive). Consequently, when every fourth year, the Romans inserted an extra or supplementary day just before the 25th of February, they called it the *bissextilis* before the Calends of March, *i.e.* the doubled sixth before March Calends. What we call leap years, they called *bissextile* years, and that name is still used in some of the languages of Europe.

The Julian calendar was a shining epoch in world chronology, not only because it cut loose from the moon, and adhered solely to the sun in the apparent rotation of that body around the zodiac, through the tropical year, but also because it purported to be a fixed and perpetual calendar, free from the intercalations of Mercedonius months every now and then.   Such a fixed calendar was of great value in ordering the work of the widely extended Roman empire along the great roads that diverged from the golden milestone in the Roman forum.   According to Julian calendar theory of Cæsar's time, the Julian almanac was fixed at 365 days, and twelve months, for an indefinite period into the future. It was understood that in every province of the empire, the bissextile day would be inserted every four years, as an *encore* to the sextilis before the Calends of March, without calling for a special calendar for leap year or change in the regular almanac program.   There may also have been popular objections to a year of even number days.

THE DATE OF NEW YEAR'S DAY IN THE ROMAN AND JULIAN CALENDARS

There is abundant evidence that the old Roman year commenced in March, but the day of New Year differed at different historical periods.   It may at one time have been the equinoctial day of March 25th.   At another time it was March 1st.   The years were commonly associated with the names of the Consuls who held office in them; so that when the new Consuls entered office, there was a tendency to make their date of entry the new year's day.   Administrative exigencies affected the date, because special consular duties might require their inauguration date to be somewhat altered.   This caused New Year's day to fluctuate accordingly. To eliminate this uncertainty, the rule was adopted about 220 B.C., fixing the New Year inauguration on the Ides of March (March 15th), but as the empire expanded geographically, this was found to be too late in the winter to enable a new consul to take up his duties, with the arrival of Spring, in some

more remote province, so the New Year inauguration was changed, in 153 B.C., to January 1st, which date remained fixed thereafter in Julian chronology. Cæsar therefore made no change in the date of the Roman New Year's day of his time. In later centuries, however, with the spread of Christianity over Europe, January 1st, as a so called pagan festival, fell into disfavor for the beginning of the year, and various church festivals were adopted in its stead, at different times and places, without otherwise departing from the Julian calendar. It was not until A.D. 1582 that January 1st was restored to its position as church New Year's day by an edict of Pope Gregory XIII, but it was not until 1799, that this restoration over Western Europe was complete. During the middle ages, various dates for the beginning of the year are found in the almanacs of churches and courts, such as Christmas, Lady Day (March 25th) and Easter. The usage differed from country to country. In spite of this confusion, however, the Julian almanac, beginning on January 1st, seems to have been maintained by historians.

In the year 44 B.C., when the Julian calendar was in full operation at Rome, the Roman senate changed the name of the old fifth month (Quintilis) to Julius, in honor of Julius Cæsar. In the same year (710 A.U.C.), the great dictator was assassinated in the Roman Senate House.

Owing to some mistake in applying the Julian leap-year rule of an extra supplementary day or bissextile day every four years, three leap days too many were introduced into the calendar count during the first thirty-six years of Julian calendar application. The error was, however, detected and corrected by cancelling and withholding three leap days in subsequent years; so that the Julian leap year count was rectified by the year 3 A.D. (756 A.U.C.)

THE AUGUSTAN CALENDAR

In the year 8 B.C., the Roman emperor Augustus, a nephew of Julius Cæsar, persuaded the Senate to alter the name of the month Sextilis to Augustus. In order to have

as many days in Augustus as in Julius, and also to avoid any misfortune attaching to an even number of days in Augustus, its days were increased from 30 to 31, by taking one day from February, which in the pre-Julian calendar had held 28 days. Moreover, since this transfer would have brought three 31-day months into immediate sequence, a redistribution was made of the days in the later months of the year as follows:

TABLE III

Augustan Modification of Julian Calendar

Month Number	Name of Month		Days in Month	Days in Quarter	Days in Half Year
	Latin	English			
1	Januarius	January	31		
2	Februarius	February	28 or 29		
3	Martius	March	31	90 or 91	
4	Aprilis	April	30		
5	Maius	May	31		
6	Junius	June	30	91	181 or 182
7	Julius	July	31		
8	Augustus	August	31		
9	September	September	30	92	
10	October	October	31		
11	November	November	30		
12	December	December	31	92	184
			365 or 366		365 or 366

Perpetual solar calendar introduced by the Emperor Augustus in 8 B.C. Twelve months and no weeks; but nundinal letters A . . . H, commencing with A on January 1st each year. Supplementary day between 23d and 24th February, with no nundinal letter, and *bis* sextile denomination.

This Augustan modification of the Julian calendar, as shown in Table III is the same as we now have, the change in A.D. 1582 to the Gregorian calendar not having affected the distribution of days among the months. It will be seen on comparing Tables II and III, that the changes made by Augustus spoil the Julian calendar both in symmetry and simplicity. In our modern calendar of Table III, the half

years differ by at least two days. The months range from 28 to 31 days, instead of from 29 to 31. Instead of having Julius' six short and six long months, we have Augustus' five short and seven long months. Instead of the short and long months following in simple alternation, the Augustan sequence is so awkward, that it is not easy to remember.

DEFECTS OF THE JULIAN CALENDAR

The Julian calendar, as modified by Augustus, began to show a defect as time went on, for a reason probably beyond Julius Cæsar's knowledge. In 46 B.C., the best available astronomical estimate of the length of the tropical year was 365¼ days (365.25) or 365 days 6 hours of mean solar time. There were no telescopes in those days, and facilities for measuring time were crude by comparison with those now available. More recent determinations[1] have placed the length of the tropical year 365.2422 days, close to 365 days 5 hours 48 minutes 46 seconds, or 11 minutes 14 seconds shorter than the estimate taken by Cæsar. This is not a large discrepancy, but it kept adding up, year after year, in the same direction. The sun would get round to crossing the equator at the vernal equinox each time nearly twelve minutes ahead of the time allowed by the Julian calendar. In five years, the sun would be nearly an hour ahead, and in 128 years, one day ahead. If the sun passed through the vernal equinox in 46 B.C. on the 25th of March, as Cæsar seems to have designed when starting his calendar, then at this rate of change, the vernal equinox would fall on the 24th of March about the year A.D. 80. Spring would thus open about one day earlier on the calendar every hundred and thirty years. When Cæsar faced calendar revision in 46 B.C., the error was in the opposite direction, for Spring opened nearly 90 days late by the old Roman calendar.

In A.D. 325, the Emperor Constantine convoked a general council of Christian prelates at Nicæa or Nice, in Bithynia,

[1] Taken as 365.24219879 for the year 1900 and very slowly diminishing (about 1 second in each 200 years, Bibliography 17).

Asia Minor, not far from Constantinople. This was the first œcumenical or universal ecclesiastical council of the Christian church, and acquired much historical importance. Its sessions lasted more than two months. Among the many matters discussed, were some relating to the Augustan-Julian calendar. The vernal equinox, which had been associated with March 25th in the early Roman calendar, and had been supposedly restored to that date by Julius Cæsar, was found to fall on the 21st of March, in A.D. 325. This has remained the reference date for the vernal equinox down to the present day. The vernal equinox of 1935 is given as at 13.18 or 1.18 P.M. G. C. T., on March 21st.

GREGORIAN CALENDAR

As the middle ages rolled by their centuries, it became increasingly evident that the Augustan-Julian calendar was somewhat too long, and that spring was arriving earlier and earlier in the almanac. Representations had been made to Pope Sixtus IV in the 15th century in favor of reforming the calendar; but no action was taken until March 1582, when Pope Gregory XIII, having satisfied himself that the equinox had retroceded to the 11th of March, or ten days earlier than on the calendar,* issued a Bull, or decree that the Julian calendar should be superseded by a new and Gregorian calendar. The change was to be made by dropping ten days from the calendar of 1582, and changing the 5th of October to the 15th. Moreover, in order to prevent the recurrence of the error in future, three leap years were to be omitted in each 400 calendar years. In preceding centuries, every centurial year such as A.D. 1500, had been a leap year, because it was evenly divisible by 4; but in the Gregorian calendar, only the centurial numbers divisible by 400 were to be leap

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* On one of the Vatican buildings at Rome is a tower called The Tower of the Four Winds (*Torre dei quattro Venti*), not ordinarily open to visitors. In this sixteenth-century tower is a room still called the Calendar Room (*Sala del Calendario*). On the floor, a meridian line was laid out and on fine days, a ray of sunlight, admitted through an aperture in the south wall, crossed the meridian line at apparent noon. The astronomer Ignazio Danti was thus enabled to demonstrate to Pope Gregory, in 1581, the ten-day dislocation between the true equinox and the calendar date.

years. Thus the century numbers of the years 1600, 2000, 2400, etc., were to remain leap years, but 1700, 1800, 1900, 2100, etc., were to be reduced to common years.

The Gregorian calendar under which we now operate, thus differs only from the Augustan-Julian calendar which preceded, through a sudden jump in the calendar, once for all, of less than two weeks, to rectify the equinox to March 21st and then the above slight change in the leap year rule, which comes into action only in certain centurial years. It has been shown that the leap year correction rule of Gregory is itself incomplete, and that it leaves a small residual error; but this is stated to be only one day in 3300 years, and can be rectified by a special adjustment of the centurial leap year rule in due time.

The astronomers credited with the mathematical work involved in the Gregorian reform are Ghiraldi of Naples and Clavius of Rome.

October 15th, 1582 is the epoch which marks the first introduction of the Gregorian calendar. The Gregorian calendar thereafter became known as the "new style" and the Augustan-Julian calendar as the "old style." These styles differed by ten calendar days in 1582. The new style was adopted immediately in Spain, Portugal, Rome and most of Italy. Most of the Catholic countries of Europe adopted it by the end of 1599. Protestant Europe began to adopt new style about 1700. Great Britain and her North American colonies changed together to new style in 1752. By that date the discordance amounted to 11 days, and almanacs of that period show that the eleven days, from September 3rd to the 13th inclusive, 1752, were suppressed; so that after Saturday the 2nd there followed Thursday the 14th. Some riots are stated to have occurred in England at the time, with the mobs shouting for the "return of their eleven days." Later still, the new style was adopted by Japan in 1873, China in 1912, Russia in 1918, Roumania in 1919, and Greece in 1923. It came out in the discussions of the League's General Conference of October 1931, that there were still

communities in Yugoslavia adhering to the Augustan-Julian
calendar; so that the adoption of the Gregorian calendar is,
perhaps, not quite complete today, more than 350 years
after Pope Gregory's "new style" was inaugurated. It is,
however, permissible to say that the Gregorian calendar is
now in substantially universal use over the civilized world.

WEEKS AND WEEK DAYS

In the old Roman calendar, the days of the month
were successively marked with the letters of the alphabet
ABCDEFGH, the letter A being attached to the first day of
the year. These cyclic eight letters were called nundinal
letters. This provided a grouping of eight days, or a sort of
8-day week. The 7-day week was imported by the Christians
into Roman chronology after the Emperor Constantine
brought Christianity to Rome in the fourth century of our
era (A.D. 321). In the middle ages, the letters a, b, c, d, e, f, g
were commonly retained in Julian almanacs, with a capital
opposite the dates of Sundays. This Sunday capital letter
was called the Dominical Letter of the year. These alpha-
betical indications practically disappeared from almanacs
after A.D. 1800 in favor of the week day letters.

The names of the week days in the Christianized Roman
empire followed the planets Moon, Mars, Mercury, Jupiter,
Venus and Saturn as still retained in the French Lundi, Mardi,
Mercredi, Jeudi, Vendredi and Samedi; but the first day of
the week was named for the Lord's Day (Domenica, Domingo
or Dimanche). In Britain, The Sun gave its name to the
Lord's Day, while the Teutonic deities Tiu, Woden, Thor and
Freya took the places of Mars, Mercury, Jupiter and Venus.

ERAS AND THEIR EPOCHS

For many centuries the Roman era dominated the chron-
ology of the European world. It reckoned in solar years from
the traditional epoch of Rome's foundation (A.U.C. or *ab
urbe condita*). There is some difference of opinion among
historians as to the epoch date. It is, however, commonly

accepted that any year N since the accepted date of Christ's birth in the Julian calendar, is year $753 + N$ A.U.C.; so that A.D. 1935 Julian, is 2688 A.U.C. Any year N in the Julian calendar, before Christ, would be $754 - N$ A.U.C. Thus, Julius Cæsar's death in 44 B.C. occurred in 710 A.U.C.

The Christian Era, with its epoch or starting point at the accepted date of the birth of Christ, is now so generally used, that it is hard to realise that it was long coming into acceptance. Historians declare that expressions such as "In the Year of Grace," or "In the year of our Lord," abbreviated to "Anno Domini" or A.D., were not introduced until A.D. 525, and it was much later before the custom was followed generally. There has been dispute over the date of Christ's birth, over a range of five years, and it is generally believed that the epoch now in use is too late by four years; but whatever the evidence may be, it is most unlikely that any change will be made in the accepted epoch; the confusion in historical literature would be too great.

The custom of assigning dates in the Christian Era before Christ, or B.C., is stated to be still more recent than the use of A.D.

The Julian calendar did not establish a new Era in Rome; it was regarded as a mere rectification of the existing Roman calendar. However, for purposes of astronomical chronology, it was proposed by Scaliger in 1582, to retain the Julian calendar with the epoch at 4713 B.C. (January 1st at noon G.M.T.). The length of each year in this Julian Period Era is just $365\frac{1}{4}$ days, as assumed by Julius Cæsar. The error in regard to the seasons of the year is thus ignored for the sake of simplicity in computation. January 1st, 1935 of the Julian calendar is thus 1st January 6648 of the Julian period. In this way, the number of mean solar days between any two events, whose dates are known in Julian reckoning, may be readily computed. Tables have been computed for finding the Julian Day Number for any assigned date. Thus the Julian Day Number for Noon G.M.T. on January 1st, 1935, is 2 427 804. $= (6648-1)(365\frac{1}{4})-13$. Thus, although the

Julian calendar had to be replaced by the Gregorian calendar after some 1600 years for civil public use, yet there is no time limit in sight for the use of the Julian calendar in chronology as a limited field.

DEFECTS OF OUR PRESENT GREGORIAN CALENDAR

The following have been frequently pointed out as principal defects of our present calendar:

1. *Monthly Irregularities.*—The months of the calendar differ in length between 28 and 31 days. The quarters differ from 90 to 92 days and the halves between 181 and 184 days. Moreover, each month contains either three or four complete weeks plus a fraction or fractions. The fraction differs with different months. See Table IV.

2. *Annual Irregularities.*—Successive years commence on different week days, as do also the halves and successive months, with the single exception that in common years February and March commence with the same week day. It would be desirable to have all weeks, months, quarters, halves and years begin on the same week day, preferably Sunday. Such an ideally simplified calendar would not only greatly simplify the selection of dates in advance for official and social events, but would also simplify statistical enquiries and comparisons of every kind.

3. *Variations in the Date of the Easter Festival from Year to Year.*—The establishment of the date of Easter Sunday is a prerogative of the Christian churches. It is an ecclesiastical function. Easter Sunday may fall on any date between March 22nd and April 25th inclusive. Easter Sunday, and twelve other subsidiary church festivals dependent upon it, are therefore called "movable feasts." The date of Easter plays an important part in the social, civic, academic and ecclesiastic programs of the Christian year. If we call April 8th a medium Easter date, the variations occurring more than, say, one week on either side (1st to 15th of April) are likely to induce disturbances in the habits and customs of

TABLE IV

A. THE PRESENT CALENDAR

Month	1st Week							2nd Week							3rd Week							4th Week							5th Week							6th Week		Month	Saturdays
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M		
Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31							Jan	
Feb				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28							Feb	
Mar				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				Mar	
Apr							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		Apr	5
May		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31						May	
Jun					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				Jun	
July							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	July	5
Aug			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31					Aug	
Sep						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30			Sep	5
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31							Oct	
Nov				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30					Nov	
Dec						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		Dec	5

The present Gregorian calendar for a typical common year (1933), which happens to open on a Sunday.
Only January and October are alike.
Three months run into six weeks.
Four months contain five Saturdays.
Five months have five Sundays.

many countries.   It would be desirable to have fixed dates
for Easter and for the festivals connected with it, so as to have
a fixed civil calendar combined with a fixed church calendar.
It has been shown that as matters stand today, the number of
different almanacs needed to provide for all the changes of
dates and week days included in church festivals, amount to
seventy [1] in all.

In order to present a typical almanac of the present
Gregorian calendar, for comparison with almanacs of pro-
posed reformed calendars, Table IV shows the almanac for
the common year 1933, which happens to have opened on a
Sunday.   This gives a fair comparison with the almanacs of
reformed calendars designed to be perpetual and so open on
Sunday invariably.   All months enter five weeks, and three
months enter six weeks.

OUTLINE HISTORY OF EASTER DATE

The Nicene General Council in A.D. 325 discussed at
considerable length the question of date of observance of
Easter; there was great dissension among the churches at
that time.   It was decided that Easter should be celebrated
on the Sunday which follows the fourteenth day of the Paschal
moon, this being the moon which shines full, on or next after
the vernal equinox.   The vernal equinox was taken as oc-
curring on the 21st of March.   Tables have been worked out
and agreed to, for determining accordingly the almanac
date of Easter Sunday in any given year.   This means that
the Easter calendar depends upon the apparent motions of
both moon and sun.   In other words, the calendar of mov-
able feasts is a luni-solar calendar.   The rule for assigning
the date of Easter Sunday has remained unchanged for more
than sixteen hundred years.   This year (1935) Easter falls on
April 21st.

Many suggestions have been made from time to time,
that the luni-solar basis of the Easter calendar should be
abolished and replaced by a solar basis like that of Christmas,

[1] Bibliography 5.

thus making it a festival as nearly fixed as its Sunday incidence permits. If a fixed or perpetual civil calendar should be internationally agreed upon, the churches might assign the Easter festival say to Sunday the 8th of April. Even if the present Gregorian calendar remained unchanged, a great simplification might be made in the church calendar by assigning Easter to the first Sunday after the second Saturday in April as was suggested by the League Committee of Enquiry.

The subject of Easter stabilization was brought to the attention of the League of Nations at Geneva in 1923.

ACTIONS OF THE LEAGUE OF NATIONS IN REFERENCE TO CALENDAR REFORM

Between the years 1900 and 1922, inclusive, various associations, commercial, ecclesiastical, industrial and scientific, had discussed the question of calendar reform and had recommended that reform was desirable on an international basis. The matter was brought to the attention of the League of Nations at Geneva, in 1922. The League referred the question to its Organisation VIII on "Communications and Transit." Organisation VIII in 1923 entrusted the question to its Advisory and Technical Committee for study and report. This important committee may here be called the A & T Committee. It considered the question at several meetings, and decided to set up a special "Committee of Enquiry" of six persons. Three eminent churchmen were appointed by ecclesiastical authorities:

The Reverend Father Gianfranceschi, President of the Academy "Dei Nuovi Lincei" (appointed by the Holy See),

Professor D. Eginitis, Director of the Observatory of Athens (appointed by the Œcumenical Patriarch of Constantinople),

The Reverend T. E. R. Phillips, Secretary of the Royal Astronomical Society of London (appointed by His Grace the Archbishop of Canterbury),

and three eminent laymen, appointed by the A & T Committee:

Jonkheer W. J. M. van Eysinga, Professor at the University
    of Leyden, Chairman,

M. G. Bigourdan, formerly Chairman of the International
    Astronomical Committee on the Calendar,

Mr. Willis H. Booth, late President of the International
    Chamber of Commerce.

The Secretary-General of the League invited comments
and opinions on the question from various governments and
religious bodies. He also sent out a questionnaire on the
subject to a large number of international organisations.

The "Committee of Enquiry" held three sessions at
Geneva: in May 1924, February 1925, and June 1926. It
carefully studied the whole question including the replies to
the League's letters and questionnaire. It decided to con-
sider separately:

1. Possible reforms in the present Gregorian calendar.
2. The fixing of movable feasts, and, in particular, the fixing
        of Easter.

Through all its subsequent investigations, the League has
adhered to this separation of the two subjects.

Having learned that certain religious sects were opposed
to plans for calendar reform that might interrupt the regular
sequence of week day names, the Committee of Enquiry, at its
session of 1925, listened to the opinions of delegares from
various Protestant delegations and also to those from a num-
ber of Jewish delegations.

The committee considered and compared the schemes for
calendar reform of which 195 had been sent in, emanating
from 54 countries.

In its report to the League of Nations, dated August 17,
1926, the Committee of Enquiry analyzed these various
schemes of calendar reform. After eliminating a large num-
ber that it considered to be impracticable, it recommended
three residual types of reform for further consideration
among the various countries, with a view to aiding the devel-
opment of international opinion toward a final selection.

As regards Easter stabilisation, it noted:

"Most of the Christian Churches have declared themselves disposed to accept the stabilisation of Easter, on condition that the measures are adopted by the various Churches simultaneously. . . . The Holy See has indeed stated that it does not think it possible, except for the most weighty reasons, to interfere with the religious traditions of centuries; but it has declared that if it can be shown that the fixing of the festival of Easter would be of universal benefit, it would submit the question to the next Œcumenical Council."

In regard to possible reforms in the present Gregorian calendar, the Committee divided them into three categories:

A. Changes retaining a Non-Perpetual Calendar, but altering the lengths of the existing months. Two plans are considered. (See Table IV for a comparison.)

1. Abolishing the 31st day of August and adding one day at the end of February. Thereafter we should have:

In common years

J	F	M	A	M	J	J	A	S	O	N	D	
31	29	31	30	31	30	31	30	30	31	30	31	days = 365
	91			91			91			92		

In leap years

J	F	M	A	M	J	J	A	S	O	N	D	
31	30	31	30	31	30	31	30	30	31	30	31	days = 366
	92			91			91			91		

2. Each quarter to have two months of 30 days and one month of 31 days; while one quarter has an additional day. One such arrangement would give:

In common years

J	F	M	A	M	J	J	A	S	O	N	D	
30	30	31	30	30	31	30	30	31	30	30	32	days = 365
	91			91			91			92		

In leap years

J	F	M	A	M	J	J	A	S	O	N	D	
30	30	31	30	30	32	30	30	31	30	30	32	days = 366
	91			92			91			92		

It may be seen that plan $A1$ is a partial return to the Julian calendar of Table III. Neither of these A plans overcomes the objections of fractional weeks included irregularly in each month, and the differences between annual almanacs.

The report points out that either of plans $A1$ or $A2$ could be effected without religious objections, and would involve but little change in existing traditions. On the other hand, the advantages to be expected from reforms of Class A are considerably less than those promised by plans B or C. The question is raised whether reforms of Class A would be worth while.

Plan B involves a perpetual calendar: *i.e.*, one in which the almanac is the same for every year; our present calendar requires a new almanac each year. Gregorian almanacs are never alike two years running. A common year of 365 days, or 52 weeks plus 1 day, will cause the next year to open one week day ahead, while a leap year of 366 days will cause the next year to open two week days ahead. If the years are to keep the same number of days as at present, we could keep a fixed or perpetual almanac by having one supplementary week day in common years, and two supplementary week days in leap years. The last day of December might go by the name of "year day" instead of a week day and on leap years instead of having an extra week day at the end of February, we might have the extra day called "leap day" say in the middle of the year. This would break up the regular sequence of weekday names at least once in each year; but it would leave the almanac fixed at 364 week days. Not only would every year commence on the same week day, say Sunday, but any particular date, such as the 4th of July would always occur on the same week day. Anniversaries would always fall on the same week day, as well as on the same month day.

Plan B, sometimes also called the "French Plan," employs a fixed calendar, and also equal quarters, neglecting the supplementary days. Each quarter would have months of 30, 30 and 31 days, or 91 days in all. The B almanac is shown in Table V. It will be seen that each quarter com-

TABLE V

B. THE FRENCH PLAN

Month	1st Week							2nd Week							3rd Week							4th Week							5th Week							Month	Saturdays
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S		
Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						Jan	
Feb			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				Feb	5
Mar					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mar	
Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						Apr	
May			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				May	5
Jun					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Jun	
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						July	
Aug			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				Aug	5
Sep					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sep	
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30						Oct	
Nov			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				Nov	5
Dec					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Dec	

Perpetual Calendar. Plan B. Equal Quarters of 30, 30 and 31 days each. One supplementary day in common years and one extra supplementary day in leap years. The supplementary days are not shown.

mences on the same week day as the year, Sunday being the preferred initial day.   Some, however, would prefer Monday. Moreover, half years and quarters contain the same full number of months and of weeks.   The supplementary year day might be inserted either after December 31st or as the o day of January following.

Plan C also involves a perpetual calendar.   Like plan B, it has a supplementary year day at the end of the year, and a supplementary leap day near the middle of the year.   It would, however, replace the 12 non-uniform months of the Gregorian calendar, by thirteen months all uniform and alike. Each month would then have, neglecting supplementary days, just four weeks or 28 days.   The new month, for which the name "Sol" has been suggested, would be inserted as the middle month of the year, between June and July.   Plan C is presented in Table VI.   It has been named by its sponsors "The International Fixed Calendar."

It will be seen that according to this fixed almanac, all years, halves, quarters, months and weeks commence with the same day, preferably Sunday.   It would therefore be easy to assign from memory alone the week day pertaining to any given date.   On the other hand, half years and quarters would not conform to the months, and would require to be expressed in weeks.   Monthly accounts, statistics and comparisons would be facilitated; but there would be 13 instead of 12 monthly accounts each year, and it would be more difficult for the peoples of the world to change to a new 13 month calendar, than to a revised 12 month calendar.   Under plan C, it might not be necessary to carry about a pocket calendar, on order to find the week day of an event, or the number of days in the year up to any given date.   On the other hand, the dislocation in anniversary dates after adopting plan C, would be considerably greater than with plan B.

The League Committee of Enquiry reported concerning plans B and C:

"Generally speaking, and considering only the intrinsic value of the last two main groups" (B and C) "the 13 month system would

TABLE VI

C. The International Fixed Calendar

Month	1st Week							2nd Week							3rd Week							4th Week							
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	
Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Feb	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Mar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Jun	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Sol	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Proposed New Month
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Aug	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Sep	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Nov	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Dec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29 "Year-day"

Perpetual Calendar. Plan C. Thirteen equal months. Each month has four weeks and twenty-eight days. One supplementary day in common years (Year Day), and one extra supplementary day (Leap Day) not shown. Thirteenth month (Sol) in the middle of the year.

seem to be of greater utility from the point of view of statistics and commerce, if the month, rather than the quarter, is to be taken as the unit of economic life.   The 12 month system would be preferable in the other contingency.   As regards the possibility of their practical application, the preliminary enquiry shows that the various Governments are more favorable to the 12 month system, which would cause less disturbance to established customs.   Most commercial establishments seem to take the same view.   An increasing number, however, seem to favor the 13 month system, particularly those which are already using it as an auxiliary calendar—a point to which we shall refer later—and have been able to gauge its results."

In regard to these auxiliary calendars, the report mentions later on that

"from the information received, it appears that a large number of important organisations (British railways and many American organisations) have already adopted various systems of auxiliary perpetual calendars, in particular, auxiliary calendars based on the 13 months of 28 days system."

The full printed report in French and English of the League's special Committee of Enquiry, which is only outlined above, is a printed document containing 163 pages. (A. 33. 1926 VIII) August 1926.   It deserves careful study.

Among the many calendar amendments suggested to the League, were some relating to the opening of the almanac, or New Year's Day.   We have seen that January 1st is an arbitrary date, arrived at by the Republic of Ancient Rome, and left unchanged by Julius Cæsar.   A more rational and systematic date would be an astronomical epoch in the year, such as one of the two equinoxes, or one of the two solstices. The French Republican calendar of 1792–1806 selected the autumnal equinox.   A number of suggestions to the League favored the Winter Solstice (December 22d).   The change would involve a dislocation in the calendar by a jump of ten days.   The disadvantages of such a dislocation were generally agreed to outweigh the advantage of greater rationality in the position of New Year's Day.   The ten day jump in establishing the Gregorian calendar was necessary, in order

to maintain the seasons; but it left a long train of disputes and litigation.

After making its above mentioned report, the special committee was dissolved, and the work of investigation was resumed by the League Organisation on "Communications and Transit" through its permanent A & T Committee.

Origins of Suggested Reform Calendars

In 1835, the Abbé Marc Mastrofini suggested a perpetual Gregorian calendar, beginning every year with a Sunday, and leaving the last day of the year blank, with no week day name.

In 1849, Auguste Compte suggested a perpetual calendar of 13 equal months, and a supplementary day at the end of the year with an extra supplementary day in leap years. The plan received very little attention at that time. A similar perpetual calendar, now called the International Fixed Calendar (Table VI) was developed by Mr. Moses B. Cotsworth in 1888. Mr. Cotsworth was born in England in 1859, and was employed in the Accounting Department of British Railways. He worked out the 13 month calendar to simplify railway statistics. After 1888 he devoted his time to calendar simplification. His calendar was endorsed by the Royal Society of Canada and by the International Chamber of Commerce. It was endorsed in 1929, by the then United States Secretaries of State, Commerce, Labor, Interior, Navy, and Treasury. The late Mr. George Eastman, of Kodak fame, also endorsed the International Fixed Calendar and became the President of the American National Committee on Calendar Reform.

The "French Plan," the "Swiss Plan" and the "World Calendar" are all fundamentally alike in offering perpetual calendars with supplementary days and equal quarters. They differ in details. The first (Table V) offers 30, 30 and 31 days per quarter, while the last two (Table VII) offer 31, 30 and 30. This "World Calendar" reasonably claims certain improvements in detail over its predecessors. Thus the last month of each quarter contains five Saturdays and

TABLE VII

THE WORLD CALENDAR *

MONTH	1st WEEK							2nd WEEK							3rd WEEK							4th WEEK							5th WEEK						
	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Feb				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Mar						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
May				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
June						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Aug				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Sept						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31				
Nov				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Dec						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

* Perpetual Almanac (Class B_1) called The World Calendar.
Four equal quarters, each having 31, 30, and 30 days.
One day added at end of December each year, and extra day added at end of June not shown.
Years, halves, and quarters all begin on Sunday.

five Sundays in the "French Plan"; but five Saturdays and only four Sundays in the "world calendar."

The world calendar is sponsored by the World Calendar Association (New York City), of which Miss Elisabeth Achelis is President.

Any perpetual calendar if adopted as starting on a Sunday, would naturally begin with a year of Gregorian Sunday opening. Such opportunities will occur in 1939 and 1950.

Actions of the League of Nations Subsequent to 1926

Convention of the Fourth General Conference by the Organisation on Communications and Transit (VIII), October 1931, to discuss Calendar Reform

The League issued in March 1931, to the various governments of the world, an invitation to send representatives to a General Conference in Geneva on October 26th, 1931. The agenda included: "Examination of the expediency from an economic and social standpoint:

(a) of fixing movable feasts;
(b) of simplifying the Gregorian calendar."

In June 1931, the League issued a printed 28 page pamphlet of preparatory Documents for the Conference (4th C. G. C. T. 1) as information and agenda. It recited recent actions in various countries on the questions (a) and (b), the disadvantages of the present calendar and the principal schemes for its reform, *i.e.* (A) Unfixed non-supplementary day calendars, (B) Fixed calendars having supplementary days, including 12 month equal quarter calendars and 13 equal month calendars. It suggested that the Conference should confine its discussions to these items. Opinions on them coming from national committees were briefly cited. The personnel lists of national committees in 27 countries were annexed.

In reference to the state of public opinion over question (a), it was pointed out that

"According to the British Committee's report, public opinion in Great Britain attaches more importance to this question than to any of the other changes that calendar reform would involve. Any scheme that did not include this stabilisation would be badly received and if the other proposed changes are to be seriously considered, it is important that the public should have an assurance that the reform in connection with the movable feasts will be carried through. Moreover, an Act of Parliament was passed in 1928 fixing the date of Easter on the first Sunday after the second Saturday in April. This Act was to come into effect on a date to be fixed by Order-in-Council. It provided for a draft order to be submitted to both Houses and approved by them. Before the draft order was framed, consideration was to be given to the official views expressed by any Christian church or institution."

The Conference met in Geneva on October 12th. The American Official Representative was Dr. C. F. Marvin, Chief, United States Weather Bureau, and Vice-President of the United States National Committee of Enquiry on Calendar Reform. The attendance was, in all, 140 persons:

From	Represented by
44 Governments	90 persons
16 Scientific and industrial organisations	26 persons
14 Calendar and religious organisations	24 persons

The President of the Conference was Dr. A. de Vasconcellos (Portugal). The Vice-Presidents were: M. Dreyfus (France) and M. Djouritchitch (Yugoslavia). The sessions extended over a week. The records and minutes of the meetings have been published by the League in a 71 page printed document C 977. M. 542. 1931 VIII. There were three plenary public sessions. Tentative agenda were presented by a Preparatory Committee, and these were adopted as follows:

a. The stabilisation of Easter.
b. 1. The disadvantages of the present calendar.
  2. The principle of the perpetual calendar.
  3. The respective advantages and inconveniences of the 12 and 13 month perpetual calendars.

At the first session, addresses were received from religious authorities, and invited organisations.

Strong opposition was made by representatives of the Jewish religion and also of one Christian sect (Seventh Day Adventists) to any plan of calendar reform which would interrupt the regular sequence of the seven days of the week. In particular, proposed perpetual calendars were objected to which involved supplementary days without week day names, such as "year day" or "leap day." Certain international religious organisations also endorsed the above views.

The general opinion of the representatives of the various countries was that Easter stabilisation was desirable, provided that all the churches agreed to adopt it simultaneously. The date proposed in the British Easter Act seemed, on the whole, to be acceptable, viz. the Sunday following the second Saturday in April.

It was agreed to express these secular opinions in an "Act" for presentation to the religious authorities concerned, by the Council of the League. This Act was issued by the League (C. 785. M. 380, 1931 VIII). The English version of the Act is appended to this paper. (See Appendix).

b. The subject of Gregorian calendar reform was discussed in the second and third sessions of the Conference. In these discussions, it soon became apparent that very few of the Governments represented had formed any definite opinion as to whether any reform of the calendar was necessary, or as to the particular plan of change that might be the best. Few of the delegates were authorised to speak definitely for their Governments. Under these circumstances, no attempt was made to reach any definite decisions by vote, except on matters of procedure.

The Preparatory Committee reported upon more than 350 plans for calendar reform, received by the League from all parts of the world, since the last Conference, i.e. between July 1st, 1926 and October 1st, 1931. These had all been analysed and classified. After eliminating duplicates and plans considered outside of the limits of enquiry, there remained 52 definite plans within the scope of discussion. Including the plans examined and presented to the Committee

of Enquiry in 1926, the League has received and examined more than 500 suggested plans.   The final analysis in 1931 was essentially the same as in 1926.   Retaining the letters used in the analysis of 1926, there were:

A. Non-perpetual calendars retaining 365 days in common years and 366 in leap years, with slight changes in the number of days in the present months, substantially as considered in 1926.

B and *C*. Perpetual calendars, with 364 days in each year and supplementary days; *i.e.* one at the end of each calendar year without week day name, always falling after Saturday, December 30th, and called, say, "Year Day" or "Year End Day," and the other every fourth year or Gregorian leap year, at or near the middle of the year, also without week day name, and called "Leap Day" or "Leap Year Day."

Plan *B* offers 12 months of four equal quarters each of 31, 30 and 30 days, sometimes called the "Swiss Plan" and also the "World Calendar."   It divides the year evenly into halves and quarters, but the months retain many of their present irregularities.   See Tables V and VII.

Plan *C* offers 13 equal months of just four weeks each. It does not divide the year evenly by months into halves or quarters; but the months and weeks are freed from irregularities.

The discussions on subject (*b*) were offered in the following order:

*b*1. Defects of the present calendar.
*b*2. Principle of the Fixed Calendar.
*b*3. Respective merits of a fixed calendar with 12 or with 13 months.

   *b*1. Views were expressed by the representatives of Italy, the Netherlands and Great Britain, that the defects of the present Gregorian calendar were not great enough to call for reform.   In discussion, however, the opposite opinion prevailed, and it was finally decided to record that the Confer-

ence in committee was of the opinion that the disadvantages of the present calendar were sufficient to justify considering the feasibility of rectifying them.

$b2$ and $b3$ were found to be so closely connected that they were virtually discussed together. As most of the Governments had formed no definite opinion, it was clearly inadvisable to seek a vote upon these questions. Many speakers, however, offered views based either on opinions of representative groups in their respective countries, or on the findings of their National Committees, etc. Many such statements clearly favored a perpetual calendar, and argued that no partial change should be made at any time, but that the major defects must be removed when the time came for making a change. It is believed that the following countries were to be listed in this group: Belgium, Canada, China, Czechoslovakia, France, Germany, Greece, Hungary, Portugal, Spain and the United States, also the International Chamber of Commerce, representing opinion in many national groups.

On the other hand, Sir John Baldwin, speaking for Great Britain, Northern Ireland and India, was unconvinced that reform was needed at present. The Netherlands and its colonies were decidedly opposed to any perpetual calendar, or any radical change, as were also Esthonia, the Free City of Danzig, Ireland and Japan. Sweden urged no change unless decided improvements over the present calendar were assured. Switzerland advocated a perpetual calendar of twelve months and equal quarters of 31, 30 and 30 days (Table VII), definitely opposing the 13 month calendar (Table VI). Several of the nations which were opposed to any radical change, might reluctantly accept the Swiss Plan. The delegate from Hungary considered that his country might accept a change that removed both main defects of the present calendar, but not a change that would remove only one.

Finally, before closing, the Conference ordered the following resolution to be addressed to the participating Govern-

ments, as a survey of its views.   The resolution is here offered
in full, because it summarises the League's impartial analysis
of the subject after eight years of study, including the ses-
sions of the Committee of Enquiry in 1926, and of the General
Conference in 1931.

RESOLUTION CONCERNING THE ECONOMIC AND SOCIAL ASPECTS
OF THE SIMPLIFICATION OF THE GREGORIAN CALENDAR.

The Conference decides to transmit to Governments invited to the
Conference the following survey of the economic and social
aspects of the simplification of the Gregorian calendar:

The Conference has taken cognisance of the report of the Pre-
paratory Committee on the question of the economic and social
aspects of the simplification of the Gregorian calendar and has
heard the statements of the representatives of the various Govern-
ments as well as the additional information supplied by some of
these with regard to the desiderata of the various National Com-
mittees.   The Conference was almost unanimous in coming to the
conclusion that the present is not a favourable time, taking into
account the state of opinion, for proceeding with a modification of
the Gregorian calendar.
Certain delegations declared that their Governments were not
in a position at the present time to form a definite opinion on ques-
tions relating to the expediency, from an economic and social
point of view, of a simplification of the Gregorian calendar.
Most of the delegations to the Conference have clearly recog-
nised that the present calendar has certain disadvantages, as ex-
plained in the report of the Preparatory Committee, and have
expressed an opinion that it would certainly be desirable, in principle,
to secure a simpler measure of time more accurately appropriate to
the needs of modern economic and social life.   A great many
delegations, moreover, thought that, as any reform of the calendar,
however moderate, would involve a rather awkward change in
century-old habits, it would be preferable not to consider any reform
which would not remedy the most serious defects of the present
calendar.   Of thirty-five delegations, eleven were of opinion that,
for instance, a mere equalisation of quarters would not be ac-
companied by advantages sufficient to counterbalance the difficul-
ties which must necessarily be encountered in connection with any
modification of traditions or any period of transition.   Four
delegations were of a contrary opinion.   It was also pointed out
that such a small change from the present calendar would not confer

any noticeable benefits on future generations. Finally, a great
number of delegations expressed the opinion that any reform of the
calendar could only be put into practice if it came into force simul-
taneously throughout the world, or at least in a very great majority
of States, and it was for this reason that the study of this question
had been placed under the auspices of the League of Nations.

The Conference examined the respective merits of the perpetual
calendars of twelve and thirteen months as set out in the report of
the Preparatory Committee. In the course of the discussions of
the Conference, it was pointed out that the thirteen-month calendar
was theoretically more perfect, particularly if appropriate measures
could be devised for the purpose of safeguarding existing contracts
during the transitional period, but that the perpetual calendar of
twelve months possessed the advantage of disturbing acquired
habits to a much smaller extent.

The introduction of supplementary days bearing no weekday
name, a necessary adjunct in practice to all perpetual calendars,
roused the opposition of various religious communities and certain
social organisations whose representatives were heard by the
Conference. Some delegations expressed the same view. Most
delegations were agreed that, failing a strong trend of opinion in
favour of a perpetual calendar, the opposition would, at least in
certain countries, make it very difficult, if not impossible, to intro-
duce the perpetual calendar. It was suggested to the Conference
in this connection that, if this situation continued, it would be
possible to make appreciable improvements in the present calendar
without introducing a perpetual calendar, by adopting a non-
perpetual calendar of thirteen months without the introduction of
supplementary days. That calendar would not permit, as accurately
as a perpetual calendar, an exact comparison of corresponding
periods in different years, but would, nevertheless, in the opinion
of its advocates, have the advantage of dividing up the year ration-
ally, and of allowing of an exact comparison to be made between
periods within the same year. It would also do away with the
drawback of having weeks irregularly divided between two suc-
cessive months in the same year.

In the same connection, the Conference's attention was drawn,
in particular, to the use, which is becoming more and more exten-
sive among large commercial and industrial undertakings in certain
countries, of an auxiliary calendar, usually based on the division of
the year into thirteen months. It was suggested that the experience
gained in this matter should be properly co-ordinated. If the use
of these auxiliary calendars became sufficiently general among
commercial and industrial organisations and among statistical

institutions, and, particularly, if they were employed by public authorities, it would gradually be possible for public opinion to perceive more clearly the consequences of a simplification of the calendar. It was also suggested that it was even possible that, if this were done, certain States in whose territories these calendars came into general use might think fit in due course to confer upon them an official character as auxiliary calendars recognised in certain official or private economic activities concurrently, at all events for a certain time, with the use of the ordinary calendar.

The Conference considered that the efforts of the Advisory and Technical Committee for Communications and Transit, through its Special Committee for the Reform of the Calendar, through the National Committees set up at its request, in consequence of a resolution of the League Assembly, and through the Preparatory Committee for the Conference, had not been in vain. For the first time, public opinion as a whole has begun to be in a position seriously to discuss the advantages and drawbacks of the simplification of the Gregorian calendar. For the first time it has begun to perceive clearly that it rested with it alone to take whatever decision it considered advisable with regard to this simplification. It is also for the first time that Governments in general have been brought to regard the simplification of the calendar as a definite question capable of discussion between them in the course of official deliberations. The preparatory work mentioned above, and also the discussions in the Conference, to which Governments will doubtless devote attention, will provide the competent Government departments with the material necessary for a considered decision.

In view of the situation set forth above, the Conference did not think fit to express any opinion on the principle of calendar reform, but the Advisory and Technical Committee for Communications and Transit will follow the efforts which will doubtless continue to be made for the purpose of enlightening opinion as to the advantages or disadvantages of a reform. It will also keep the Governments regularly informed on the matter. It will thus continue its task, which has always consisted, not in any particular propaganda, but in the impartial enlightenment of public opinion on an economic and social problem which, as experience has shown, and whatever the arguments advanced for or against the reform of the calendar, arouses a lively interest in a large number of countries throughout the world.

The above resolution is the last official document on Gregorian Calendar Reform issed by the League up to date,

being printed in Document C. 785. M. 380, 1931 VIII, dated
October 24th 1931.

EVENTS SINCE 1931 RELATING TO THE QUESTION OF EASTER
STABILISATION

In accordance with the Act of the Fourth General Con-
ference, as already quoted, and appended in full, the Council
of the League brought the Act to the attention of ecclesiastical
authorities bespeaking their favorable consideration. In
document C. 335. M. 154, 1934 VIII, dated August 3, 1934,
the League published a summary of the replies received.

In regard to the attitude of the Holy See, it is noted:

"By letter dated December 30, 1932, Cardinal Pucelli informed
the Secretary General that the Holy See maintains the point of
view already expressed in previous communications: *i.e.* that the
stabilisation of Easter is a pre-eminently religious question which
falls within the competence of the Holy See and that, for reasons of
higher spiritual concern, the Holy See cannot contemplate a change
in the matter."

Unfortunately, this attitude appears to be inconsistent
with the report of the Committee of Enquiry in 1926, pre-
viously quoted, which declared "if it can be shown that the
fixing of the festival of Easter would be of universal benefit, it
would submit the question to the next Œcumenical Council."

On the other hand, the attitude of a large number of
Christian churches outside of the Holy See was summarised in
five articles of which the first three are as follow:

"I. The overwhelming majority of the Churches agree that objec-
        tions of a fundamental nature to a stabilisation of Easter
        cannot be raised.
 II. The overwhelming majority of the Churches make their agree-
        ment to the stabilisation of Easter dependent on the fact
        that a general agreement between the Christian Churches
        on the question can be reached.
III. To the proposal of the League of Nations to fix Easter on the
        Sunday following the second Saturday in April, the vast
        majority of the Christian Churches do not raise any ob-

jections; while a very considerable proportion of them definitely express agreement."

The last named document of August 1934 is the latest publication of the League relating to Easter stabilisation to this date (April 1935).

In August 1934, the Universal Christian Council of Churches in America unanimously adopted four resolutions relating to Easter Stabilisation and to Calendar Reform. The first reads as follows:

"The Universal Christian Council agrees that in any calendar reform and new regulation of the date of Easter, the disturbances and distress in social and economic life caused by the changing date of Easter should be restricted to a minimum and that therefore in any such new regulation the Festival of Easter should be definitely stabilised on a fixed date, on condition that it should always fall on a Sunday."

CONCLUSION

It may well be claimed that the very numerous expressions of opinion secured through the channels of the League, from all parts of the Christian world, show a strong and general belief that the present wide variations of Easter in the Church calendar produce, in the aggregate, much inconvenience, disturbance and expense to all the Christian countries directly, and to non-Christian countries, in lesser degree, indirectly. The League has opened an opportunity for granting a great and gracious boon to all humanity, if the authorities of the Christian Church would consider the question of abandoning the lunar portion of the existing Church Calendar, thereby reducing it to a purely solar calendar. The disturbing influence of the vagrant moon has been a burden on the Christian world for more than sixteen centuries. The change lies within their power to effect, without altering the civil Gregorian calendar. The League has shown that no universal international agreement on changes in the Gregorian calendar can be looked for at present and that much more study must be given to the subject before the various governments can crystallise their opinions for a

vote.   Any change which was not universal would annul the
great advantage of the present Gregorian civil calendar, *i.e.*
its universality.   Pope Gregory XIII earned lasting grati-
tude and fame for his leadership in correcting the Julian
calendar in accordance with the best astronomical knowledge
of the sixteenth century.   At that time, 1582, opposition to
the change developed among the branches of the Christian
Church, and the change is even now barely complete.   At
this time, no opposition appears to Easter stabilisation, if the
Christian Church Authorities would grant it.

APPENDIX.

Act Regarding the Economic and Social Aspects of Fixing Movable
Feasts

Whereas this Conference is called upon to give its opinion on the
expediency from an economic and social standpoint of stabilising the
movable feasts;

And whereas the present instability of movable feasts disturbs
the regularity of industrial, financial, commercial and judicial
activities, as well as the application of a normal plan of school and
university studies;

And whereas, the Easter season being almost universally a
holiday period, the stabilisation of this festival at a suitable time
would offer genuine advantages to the population as a whole, and
especially to employers and employees in all branches of industry,
finance and commerce;

And whereas large sections of the population, and particularly
economic circles and those interested in education, have expressed
the almost unanimous desire that movable feasts should be fixed;

And whereas stabilising the movable feasts is a pre-eminently
religious question and any solution of the problem therefore depends
on the free decision of the religious authorities;

And whereas the Conference has noted that, according to the
views expressed by the Special Committee on Calendar Reform,
which included representatives appointed by the Holy See, His
Holiness the Œcumenical Patriarch, and His Grace the Archbishop
of Canterbury, consideration of calendar reform, as regards both
the stabilisation of Easter and the more general question of the
reform of the Gregorian calendar, does not encounter difficulties
which can be regarded in advance as insurmountable;

And whereas the Conference has also noted that, by a letter dated March 7th, 1924, sent to the Secretary-General of the League of Nations through the Apostolic Nuncio in Switzerland, the Holy See announced that, if it were proved that the general welfare called for changes in the venerable traditions at present followed in determining ecclesiastical feasts, particularly the feast of Easter, the Holy See would only examine the question on the preliminary recommendation of an œcumenical council;

And whereas, in the preliminary proceedings, the other religious bodies interested have raised no objection to the fixing of movable feasts, provided that such reforms meet with the approval of all the Christian Churches;

And whereas it is the duty of the Conference to voice the opinion of the Governments on the secular aspects of stabilising Easter and the movable feasts dependent thereon;

The General Conference declares that the Governments whose representatives at the Conference have voted for this declaration, or which inform the Secretary-General of the League of Nations before May 1st, 1932, that they endorse this declaration, consider, from the economic and social standpoint, that the common good calls for the stabilisation of movable feasts.

As regards the day that might be selected for the feast of Easter, most of the Governments whose representatives have expressed any opinion on the matter have pronounced in favour of the Sunday following the second Saturday in April.

The Council of the League of Nations is asked to bring this Act to the notice of the religious authorities concerned, expressing the hope at the same time that they will consider in the most favourable spirit what action they may take in the matter.   The Council is also requested to notify the Governments invited to the Conference, before April 30th, 1933, of any views expressed by the religious authorities on this Act and on the action which they may propose to take upon it.

BIBLIOGRAPHY

1. Encyclopædia Britannica, 11th ed. 1911.
2. Larousse du XX⁰ Siècle.
3. Enciclopedia Italiana 1930.
4. Series of League of Nations Documents, Communications and Transit Organisation 1924 to 1934.
5. Kalendar-Compendium, O. Fleischhauer, Gotha, 1884.
6. Chronologie, E. Cavaignac, Payot, Paris, 1925.
7. The Americana, vol. V.
8. The Calendar, Its History, Structure and Development, A. Philip.   Camb. Univ. Press, London, 1921.
9. The Beginning of the Year in the Middle Ages.   R. L. Poole, Proc. British Academy, vol. X, Nov. 1921.

10. Handbuch der Chronologie. F. K. Ginsel, Leipzig, 1911.
11. The Calendar, J. K. Frotheringham, Nautical Almanac, London, 1931 and 1935.
12. Journal of Calendar Reform, New York City, five volumes. 1930-1935.
13. Clavis Calendaris. J. Brady, 2 vols. London, 1812.
14. Les anciens Almanacs, V. Champier, Paris, 1886.
15. The American Nautical Almanacs, 1900-1935.
16. Annuaire du Bureau des Longitudes, Paris, 1900-1935.
17. Smithsonian Physical Tables, 8th ed. Smithsonian Inst. 1932.

CRYPTASPIS AND OTHER LOWER DEVONIAN FOSSIL FISHES FROM BEARTOOTH BUTTE, WYOMING

WILLIAM L. BRYANT

(Read by title April 19, 1935)

A CHANNEL filled with sediments of Lower Devonian age was discovered some years ago at Beartooth Butte, Wyoming. Entombed therein have been found the remains of a remarkable assemblage of the most primitive plants and vertebrate animals accompanied by Eurypterids. Some of the latter attained a length of three or four feet. Twenty-eight new species of fossil fishes included in thirteen genera, have been described from this ancient watercourse, which thus proves to be one of the most important depositories of primitive vertebrates in the world.

From all of the available evidence Dr. Erling Dorf, who first discovered this ancient channel and who led several expeditions thereto in search of fossils, has concluded that "the sediments of the channel fill were deposited in fresh or brackish water under estuarine conditions in a drowned river valley." [1]

It appears that quiet water in which fine calcareous sediments were deposited prevailed during most of the history of this river valley. At times, there was considerable submergence; at other times the waters became quite shallow, as evidenced by numerous mud cracks. All of the flora consists of land plants, of which the fragile and delicate parts have been hardly damaged in transportation. All of it belongs to that primitive group, the Psilophytales.

Turning to the fishes, we find fine, large species, several groups of which average far larger than their nearest European relatives. These include Ostracoderms, Sharks, and Arth-

[1] Erling Dorf, "Stratigraphy and Paleontology of a New Devonian Formation at Beartooth Butte, Wyoming." *Journal of Geology*, Vol. XLII, No. 7, 1934.
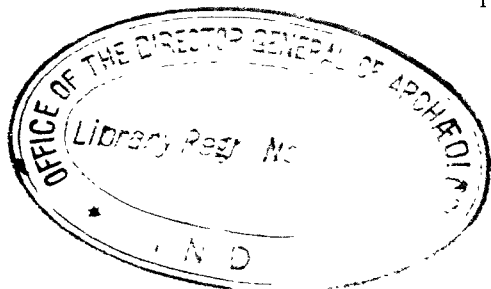
rodires.   Only the bony armor and scales of these fishes are preserved, but in some head-shields we have the delicate impressions caused by portions of the brain and other organs.

Merostomes are rare in these deposits.   Two genera, each represented by a single species, with few examples of each, thus far have been discovered.   One of these attained considerable size, exceeding in length most of the fishes, which must have found in it a formidable competitor.   A description of these Eurypterids by Dr. Rudolf Ruedemann will be appended to this paper.

A Princeton expedition to Beartooth Butte during the summer of 1934 brought home a further collection.   This collection, while containing few new forms, is important because of the fine preservation of many of the specimens, giving more detailed information concerning a number of species.

The vertebrate fossils were loaned to me for study by Professor William J. Sinclair of Princeton University.   It is the purpose of this paper to communicate the additional knowledge afforded by the most recent collections, and to describe such new species as have come to light.

Order *Heterostraci*
Suborder *Cyathaspida*
Genus *Cryptaspis* Bryant

In his unfinished work on the *Cyathaspida*, an abstract of which was published by Heintz in 1932,[1] the late Professor Johan Kiaer divided the suborder into two tribes, the *Poraspidei* and the *Cyathaspidei*.   In the first tribe, the dorsal shield is always entire and undivided; in the second tribe, the dorsal shield is more or less distinctly divided into four parts.   Prior to the discovery of a dorsal shield of *Cryptaspis* in the Lower Devonian beds of Beartooth Butte, it was supposed that the *Cyathaspida*, which appeared for the first time in the marine Silurian of Europe and North America, had disappeared with the close of the Downtonian.   The

[1] Johan Kiaer, "The Downtonian and Devonian Vertebrates of Spitzbergen." IV. Suborder Cyathaspida. Kong. Dept. Handel, Sjofart, Industri, Handverk og Fiskeri; Skrifter om Svalbard og Ishavet. Oslo, 1932. No. 52.

genus *Cryptaspis*, therefore, includes the youngest known members of the *Cyathaspida* as well as the largest forms yet found.

The present genus, *Cryptaspis*, was established by the writer [1] on a unique dorsal shield, several branchial plates, and a fragment supposed to have been part of a ventral shield. While the type dorsal shield exhibited a nearly complete sensory canal system with impressions of the pineal organ and of several branchial sacs, certain important diagnostic features were not apparent in this specimen. The collections made last summer (1934) include several dorsal shields. These afford much new information concerning the structure of this fish and make possible the following amended diagnosis of the genus:

This includes comparatively large forms belonging in the family *Poraspidæ*. The dorsal shield is entirely undivided and weakly vaulted. The lateral margins bend abruptly downwards and slightly inwards. The rostral region is short, broad, and unconstricted. There is no terminal beak. The well developed maxillar brim is broad and flat. In the branchial part each lateral margin of the shield is bent outwards to form a rounded shelf. Above this the shield is pierced for the branchial opening which is thus wholly enclosed within the dorsal shield. The post branchial part is short. The posterior margin of the shield is thickened, terminating in a short flat median lobe. The orbits, placed far forwards, are directed laterally and are partially bounded by notches in the margins of the shield. The dentine ridges are fine and flat above, but laterally crimped. In the rostral region they are arranged fanwise; elsewhere they run in subparallel, longitudinal rows, separated by minute grooves. The dermal skeleton is thin with well developed cancellous layer. On the the inner surface of the shield are to be seen impressions of the nasal sacs, the pineal macula, the semicircular canals, the hind brain, and the branchial sacs. The branchial plates are

[1] William L. Bryant, "The Fish Fauna of Beartooth Butte." Part III. *Proc. Amer. Phil. Soc.*, Vol. LXXIII, No. 3, 1934.

very short. They are located directly below the lobes, in which are contained the branchial orifices, and are bounded on three sides by the margin of the dorsal shield. On the lower side they are in contact with the lateral margin of the ventral shield throughout their length. They exhibit distinct areas of overlap on both longitudinal margins.

Unfortunately nothing is known of the posterior half of these fishes. Scales and fins have not yet been found. Plates in the suborbital region and mandibular elements are also unknown.

The genus *Cryptaspis* resembles in many ways the Spitzbergen *Poraspis*. But while in *Poraspis* the branchial plates are long and slender, extending almost to the orbital region, in *Cryptaspis* they are short and rather wide. In *Poraspis* the branchial opening is located between the lower margin of the dorsal shield and the upper margin of the branchial plate. In *Cryptaspis*, the branchial opening is wholly enclosed within the dorsal shield. It may be that these and other characters are of family value, but as I have found considerable variations in the proportions of branchial plates clearly belonging to this genus, I believe that for the present *Cryptaspis* should be included with the *Poraspidæ*. *Cryptaspis* is the most primitive fish of Beartooth Butte. Its nearest American relative is *Palæaspis* from the Silurian of Pennsylvania.

<center>*Cryptaspis ellipticus* Bryant</center>

<center>Pls. I–V; Pl. VI, Fig. 1; Text Fig. 1</center>

Among the collections made at Beartooth Butte last summer (1934) are a number of more or less well preserved dorsal shields of *Cryptaspis ellipticus*. The best of these, (No. 13844), is partially preserved in counterpart. Pl. I shows a natural cast of the inner surface of the dorsal shield. The greatest width of the shield is found at the expanded branchial lobes, which are located rather far back on the sides. From this point the shield narrows in both directions, gradually towards the blunt snout and more rapidly towards the rear, where it terminates in a blunt median lobe. It is only

weakly and uniformly vaulted above, but the sides of the shield are flexed sharply downwards and inwards, except below the branchial openings where they project outwards in rounded lobes. Beneath these lobes the lateral walls of the shield are excavated to receive the branchial plates which they embrace on three sides. The lateral flanges are about 5 mm. in width. The lateral and posterior margins of the shield are thickened. Across the posterior margin this thickness forms a rather broad band.

The greatest length of this specimen is 78 mm. Its greatest width is 44 mm. (restored). The rostral length is 9 mm. and the pineal length is 15 mm. According to the system of measures proposed by Kiaer,[1] the breadth-length index is therefore 56 and the rostral index is 11.

A feature conspicuous in this fossil is the broad maxillary brim, extending almost from orbit to orbit, and, no doubt, marking the boundaries of the terminal mouth. An enlarged view of it will be found on Pl. III. The functional surface is strongly rugose. There are no impressions left by the nostrils, but on the counterpart of this specimen, seen on Pl. II, are a pair of large, rounded impressions directly behind the maxillar brim. These were undoubtedly caused by the olfactory organs.

The eyes were situated far forward on the sides of the head and were directed laterally. They are partially enclosed by notches in the flexed lateral margins of the shield and are hardly visible when the shield is viewed from above. On the natural cast of the inner surface of the shield, shown on Pl. III, they are seen as prominent rounded tubercles retaining their original shape. The pineal macula is always large, prominent, and is longer than wide. It is located rather far back on the head. Impressions caused by the semi-circular canals are not well shown on this specimen, but they are conspicuous on another specimen (No. 13845), shown on Pl. V.

The well defined median impression apparently caused by

[1] Op. cit. p. 10.

the hind brain or nerve cord, conspicuous on Pl. IV, Fig. 2, is remarkable for its length, extending well behind the branchial lobe. The anterior termination of this impression is not distinct, but it arises just behind the semi-circular canals.

In nearly all dorsal shields the impressions after the branchial sacs are more or less well preserved. The best example of these is exhibited on the specimen figured on Pl. V, where six paired impressions are seen. The peculiar branchial opening is well shown on only one specimen—the natural cast of the inner surface of the shield in specimen No. 13844. Unfortunately, the counterpart of this specimen was broken away at this point, leaving one in doubt as to the outer configuration of the opening. Apparently there were two branchial orifices on each side, consisting of elongated slits upon and above the branchial lobe. One of these openings arises above the other and curves downward beyond it. The orifices of the right side are shown on Pl. IV, Fig. 2.

The sensory canals system of the dorsal shield is illustrated in the attempted restoration (Text Fig. 1). These canals are usually seen on specimens as open grooves, but actually they were situated within the test and communicated to the surface by means of rather large closely spaced pores. Usually the canals do not run in straight lines, but while arranged in the same pattern, meander somewhat differently in various specimens. There seems to be a definite relation between the transverse canals and the branchial sacs.

Branchial plates have been found in direct association with dorsal shields in two specimens. One of these was illustrated in a former paper. The other, a left branchial plate, is to be seen behind its original position, on Pl. II. It measures 20 mm. in length by 8 mm. in width. The upper margin is slightly convex and the lower margin slightly concave, to agree with the contours of the dorsal and ventral shields. The branchial plate was overlapped on three sides by the dorsal shield, and on the fourth by the ventral shield, as shown by distinct areas of overlap. Just below the branchial lobe, the lateral margin of the dorsal shield is
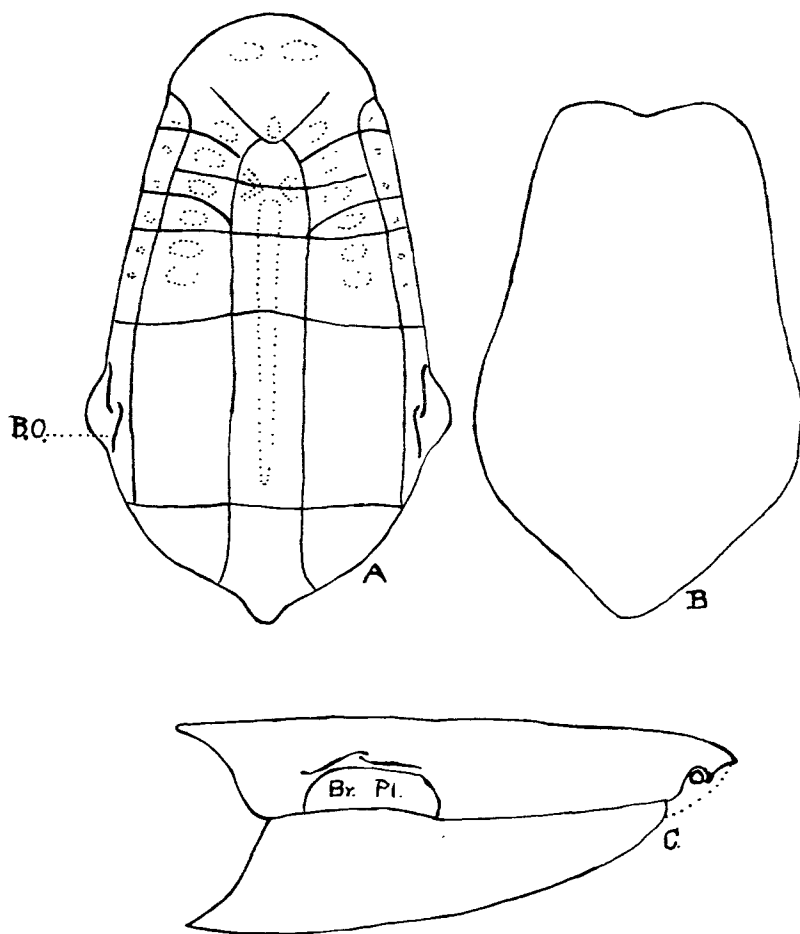
TEXT FIG. 1.   *Cryptaspis ellipticus* Bryant.   Outline drawing of the dermal skeleton.   A, dorsal shield; B, ventral shield; C, lateral view of dorsal and ventral shields, showing position of the branchial plate.

The course of the sensory canals on the dorsal shield is shown by solid lines. Impressions on the visceral surface of the shield are shown as dotted lines.   Bo, slits in the dorsal shield above the branchial lobe.   × 1.

deeply excavated to receive the branchial plate, of which the relation to dorsal and ventral shields is shown in Text Fig. 1.

Only fragments of the ventral shield in this species have been found.   The specimen shown on Pl. IV, Fig. 1 is the best of these.   It exhibits the front half of a ventral shield,

which is seen to be rather deeply vaulted. It is emarginate in front, where there is an articular area, apparently for the mouth plates. There are no sensory canals or impressions of branchial sacs preserved in this specimen.

The superficial ornamentation in this species has already been described and illustrated.[1] It only remains to add that about five dentine ridges are contained in 1 mm. On the front margin of the shield these ridges are somewhat enlarged and their terminations have a toothlike appearance. These denticulations may in fact have been functional (Pl. VI, Fig. 1).

Cryptaspis flabelliformis n. sp.

Pl. VII

Type: A nearly complete ventral shield in grey limestone (No. 13888).

This species is founded on a nearly complete ventral shield of comparatively great size. It is uncrushed except for a single longitudinal fracture. The shield measures 100 mm. in length and 83 mm. in greatest width, which is at a point rather far back. Each lateral margin of the shield at the point of greatest width forms a gently rounded lobe to conform to the shape of the branchial plate which it overlaps. Thence the shield rapidly narrows with almost straight margins towards the front, where it measures only 37 mm. in width. The anterior end is emarginate. The hinder portion of the shield tapers rapidly to a rather sharp median lobe.

The shield is arched in all directions, gently so from front to rear. From side to side, it is almost flat across the front, but rapidly arches towards the region of greatest width, where the sides are well flexed. The extreme posterior portion of the shield is also nearly flat from side to side.

The "bone" composing the shield is extremely thin, less than half a mm. in thickness. The superficial ornament consists of flat topped ridges, the sides of which are crimped.

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[1] W. L. Bryant. "The Fish Fauna of Beartooth Butte, Wyoming." Part I. The Heterostraci and Osteostraci. Pl. XVII, Fig. 2. *Proc. Amer. Phil. Soc.*, Vol. LXXII. No. 5 1933.

Less than four of these ridges are contained in one mm. and they are separated by extremely narrow grooves. The ridges are subparallel and generally run in a fore and aft direction. In some places, however, they are greatly contorted notably so towards the front.

Sensory canals are not preserved and there are no impressions of branchial organs. This shield clearly pertains to a new species. It represents a form, more than twice as large as *Cryptaspis ellipticus*. The dorsal shield must have been much wider in its posterior moiety than that of the latter species, and the ventral shield was not so deeply arched, especially in front.

<div align="center">

Cryptaspis sp.

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Among the last summer's (1934) collections are a number of detached branchial plates. Some of these, while exhibiting the generic characters of *Cryptaspis*, differ from each other so decidedly that they clearly pertain to various species, some of which must be new. Some of these plates are narrow and elongated. Others are short and wide. Some are straight, while others are curved. On Pl. VIII, Figs. 1 to 3, I have figured a few of these branchial plates. It will be observed that the plates show practically continuous areas of overlap. On the dorsal margin the overlapped areas are the widest. It is probable that the specimen shown in Fig. 1 is the branchial plate of *C. flabelliformis*. The others may belong to species whose dorsal and ventral shields have not as yet been found. In all, the dentine ridges run obliquely downwards and forwards across the plate.

<div align="center">

Genus *Cardipeltis* Branson and Mehl

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This genus was founded in 1931 by the above mentioned authors,[1] on a large dorsal shield found in the lower member of the Jefferson formation at Blacksmith Fork, Utah. From a microscopical examination of the exoskeleton, these authors

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[1] E. B. Branson and M. G. Mehl, "Fishes of the Jefferson Formation of Utah." *Journal of Geology*, Vol. XXIX, No. 6, 1931.

placed this genus among the *Heterostraci* and compared it with the Silurian genus *Palæaspis*, with which it agreed in having the dorsal shield entirely undivided and to a lesser extent in the character of its ornamentation. Subsequently, the present author[1] described two more species from the Lower Devonian of Beartooth Butte and proposed to group the various species in a new family, the *Cardipeltidæ*. Certain structural features indicate that this family belongs in the tribe *Poraspidei* of the sub-order *Cyathaspida*.

A striking peculiarity in *Cardipeltis* consists in the curious paired notches found on the lateral margins of the shield, about midway of its length. These were described as orbital notches by Branson and Mehl and this interpretation was followed by the writer. A closer study of these notches has now convinced me that they have nothing to do with the orbits, but that they mark the position of the branchial openings. Continuous with each notch is a deep furrow excavated in the bone and directed obliquely backwards and inwards. On Pl. IX, Fig. 1 may be seen a view of the left lateral notch of *C. oblongus*. The groove is partially obscured by the matrix, but it will at once be evident that this sinus has none of the usual characters of an orbital notch. On the other hand, it would seem to be well adapted for the boundary of a branchial outlet. If this interpretation be true, as I believe, then the position of the eyes in *Cardipeltis* is still unknown and the branchial organs were located well forward, below the anterior half of the dorsal shield.

The exoskeleton in species of *Cardipeltis*, found at Beartooth Butte, is exceedingly thin. In one specimen, found last summer (1934), the superficial ornamentation has largely weathered away, leaving its impression in the matrix. In this specimen, shown on Pl. IX, Fig. 2, one sees that the bases of the sculptured ridges were laterally crimped, exactly as in most of the other *Heterostraci* found in this locality. This

[1] W. L. Bryant, "The Fish Fauna of Beartooth Butte, Wyoming." *Proc. Amer. Phil. Soc.*, Vol. LXXII, No. 5, 1933.

effect is also duplicated in the European genus *Weigeltaspis*, recently described by Brotzen.[1]

A small, oblong, but apparently complete plate or scale bearing the characteristic ornamentation of this genus was found last summer (1934) and is illustrated on Pl. VIII, Fig. 4. It is impossible to determine where on the body of *Cardipeltis* this plate was situated. It somewhat resembles the branchial plate in *Cryptaspis*, but seems too small for the large shields of *Cardipeltis*. It may have been a dental plate.

Family *Protaspidae*

This family is represented in last summer's (1934) collections by a number of finely preserved specimens. Among them are a few detached median dorsal and orbital plates belonging to juvenile individuals. These exhibit the sensory canal system with remarkable clarity. In adult individuals the canals are usually more or less obscure, and as preserved, are recognized only by a slight thickening of the bone above the channels. In juvenile specimens with extremely thin tests, the sensory canals are readily discernible.

On Pl. X, Fig. 1 I have illustrated the median dorsal plate of a young specimen of *P. bucheri*. The oblique paired canals are more widely spaced and more nearly horizontal than they appear to be in adult specimens. The anterior pair of these canals must have entered the lower arm of the orbital plate. Behind them a nearly horizontal pair is directed outward, towards the branchial plates. A third pair of canals run obliquely backwards terminating at the posterior lateral corners of the shield. All of these canals join or cross a median longitudinal pair which, originating on either side of the median dorsal spine, traverse the plate from one end to the other. For comparison I have illustrated on Pl. XI, Fig. 2, the median dorsal plate of a juvenile specimen of *Cyrtaspis ovatus*, showing well the sensory canals in the mid-dorsal region.

[1] Fritz Brotzen, "Weigeltaspis nov. gen. und die Phylogenie der Pauzertragenden Heterostraci." Sonder-Abdrick aus dem Centralblatt f. Min. etc. Jahr. 1933 Abt. B, No. 12.

Sensory canals in the orbital region hitherto have not been observed in the *Protaspidae*. In our newest collections are several detached orbital plates on which the sensory canal pores are visible. Two of these plates, belonging to un-determined species, are figured on Pl. XII, Figs. 1, 2. A sensory canal, originating on the median dorsal plate, enters the orbital plate at the inner margin near the posterior end. Thence it runs forward, giving off branches which partially encircle the orbit. From thence a line runs across the dorsal arm of the orbital plate towards the pineal plate. This arrangement somewhat resembles that described in *Pteraspis Smith-Woodwardi* by Broili.[1]

<center>Genus *Protaspis* Bryant</center>

The nearly complete armor of a large specimen of *Protaspis bucheri* is illustrated on Pl. XIII. In this specimen the dorsal shield is largely uncrushed. The rostral plate lacks its anterior termination, and the free end of the median dorsal plate has broken away. The pineal and orbital plates are well shown and the right orbital opening is conspicuous. Its borders are raised above the surrounding surface. The median longitudinal sensory canals can be seen distinctly. They run parallel to each other on the forward part of the shield and are so close to each other that they enter the pineal plate on either side of the pineal macula.

The ventral shield of this specimen is also nearly complete and little crushed. It has slipped from its original position and lies at an angle with the dorsal shield, and partly beneath it. The dorsal shield has been crushed upon it at this point so that the complete outline of the ventral shield is preserved. The vaulting of this shield is slight, whereas that of the dorsal shield is high.

A fragment apparently referable to this species and show-ing a portion of the squamation of the body is shown on Pl.

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[1] F. Broili, "Der Gattung Pteraspis in den Hunsruckschriefern." Litzunberichte der Bayerischen Akad. der Wiss. Math.—natur wis. Abt. Sonder. aus dem Jahrg. 1933.

XI, Fig. 1. The very large, pointed dorsal and ventral ridge scales resemble those in the European *Anglaspis*. The intervening space is occupied by much smaller but less attenuated scales. A detached ridge scale is illustrated on Pl. IX, Fig. 3.

One of the largest of the Beartooth fishes is *Protaspis amplus* Bryant, hitherto known only by the type specimen, a crushed dorsal shield. A second and much larger example of this fish was found last summer (1934), and is pictured on Pl. XIV. The dorsal shield in this specimen measures 18 cm. in length and indicates a fish more than two feet long. The dorsal shield is preserved in visceral aspect and is deeply vaulted. Both lateral margins have broken away but the left cornual plate is preserved. The rostral plate is very long. In the present specimen it is contained only a little more than three times in the length of the shield. The spinal plate is long, narrow, and high at the distal end. A vacuity, which apparently marks the position of the branchial orifice, occurs just in advance of the cornual plate and at the outer termination of the oblique, trough-like depression, which extends from the anterior end of the spinal plate to the postero-lateral angle of the shield.

A nearly complete dorsal shield of *Protaspis brevirostris* Bryant is illustrated on Pl. XV. The shield is almost uncrushed. All of the component plates are distinctly demarcated. The shield is well arched, the highest vaulting occurring at a point in the median line distant from the posterior termination, twice the length of the spinal plate. The rear end of the median dorsal plate terminates in a broad, depressed lobe. Certain impressions caused by the sensory canals are visible on the surface of the plate. The branchial plates are very narrow and almost uniform in width throughout their length.

The genus *Cyrtaspis* is represented in the latest collections by a number of dorsal and ventral shields in a fine state of preservation. *Cyrtaspis ovatus* Bryant, the type species, has hitherto been known only by fragmentary specimens. A

complete dorsal shield of this species was collected last summer (1934) and is illustrated on Pl. XVI. The rostral plate is not so large in proportion to the entire shield as was supposed, being contained nearly four times in the total length of the shield. The long, slender dorsal processes of the orbital plates are well shown on this specimen. The median dorsal plate is crushed nearly flat. A pair of trough-like grooves, originating just in advance of the spinal plate, and becoming wider as they proceed, diverge obliquely out-wards to the postero-lateral angles of the median dorsal plate. Their outward terminations also mark the termi-nation of the branchial plates and presumably the location of the branchial openings. Similar paired grooves occur in several other Protaspids, i.e. *Protaspis amplus* and *Cyrtaspis papillatus*. They recall the grooves leading upwards from the branchial notches in the shield of *Cardipeltis*.

INCERTAE SEDIS

In a former paper[1] I illustrated a fragmentary plate bearing impressions of what seemed to be the sensory canal system of some unknown form. Since then, two other ex-amples have been found. They are equally unsatisfactory in that they exhibit only the inner layers of the bone with none of the superficial ornamentation preserved. They are illustrated on Pl. XVII, Figs. 1, 2. The meandering lines shown in Fig. 1 are actually minute tubes. Sir Arthur Smith-Woodward has suggested to me that these remarkably irregular tubes may be post mortem borings produced by some kind of parasite, perhaps a sponge or a fungus. The badly preserved condition of these bones, as though they had been lying on the bottom for a time, unburied, would support this view.

A small, oblong, slightly curved plate, found last summer (1934) and illustrated on Pl. XII, Fig. 3, evidently belongs

[1] W. L. Bryant, "The Fish Fauna of Beartooth Butte, Wyoming." Part I. The Heterostraci and Osteostraci. *Proc. Amer. Phil. Soc.*, Vol. LXXII, No. 5, 1933. P. 311. Pl. XXI, Fig. 1.

to some undescribed member of the *Heterostraci*. The plate, which is apparently complete, resembles in shape the branchial plates of *Cryptaspis*, but lacks the characteristic overlapped areas; the dentine ridges, which in *Cryptaspis* are obliquely transverse, are arranged longitudinally on the present specimens. At each end of the plate the ridges tend to break up into flat tubercles in a manner suggestive of *Protaspis perryi*. Still another innominate plate is illustrated on Pl. VI, Fig. 3. The lines inscribed on this plate are suggestive of certain markings found on head plates of *Dipterus*.

<p style="text-align:center">Order *Arthrodira*</p>

<p style="text-align:center">Family *Acanthaspidae*</p>

All of the Placoderms found at Beartooth Butte are Acanthaspids, the most primitive group among the Arthrodires. Two genera, *Euryaspis* and *Anarthraspis*, have already been described, with a number of species. The superficial structure of these forms is fairly well known from abundant material. Unfortunately, the bones composing the dermal skeleton of the trunk in these fishes have always been macerated away from each other and from the head-roof, and have been scattered about before petrification. It thus becomes extremely difficult to assign detached body plates to any particular form of head-roof. The various species of *Euryaspis* are especially confusing in this respect, inasmuch as the ornamentation is identical in all forms. On the other hand, the bones composing the head-roof in the various species are so solidly fused together that it is usually impossible to distinguish their true outlines. One of the occasional exceptions is found in the head-roof illustrated on Pl. XVIII, Fig. 2, on which the outlines of the large pineal, and of the median basal plates are easily visible. In this head-roof the median basal plate is seen to be about twice as wide as long, overlapping the externo-basal plates to a considerable extent and reducing their exposed area correspondingly. The median basal plate in this form thus resembles that in *Dinichthys*, whereas, in head-roofs tentatively assigned to *Euryaspis*

brachycephalus Bryant, the median basal plate is quite narrow, being longer than wide. It is possible that the present head-roof belongs with the median dorsal plates heretofore described under the name of *Euryaspis cristatus* Bryant.

Euryaspis major n. sp.

Pl. XVIII, Fig. 1; Text Fig. 2

Type: A head-roof embedded in yellow limestone (No. 14183).

The unique head-roof upon which this species is founded is preserved in visceral aspect. Around the margins of the head, the bone has broken away, exposing an impression of the ornamentation. The lateral margins unfortunately are imperfect, and the restored outline of the head, found in Fig. 2, is therefore only approximately correct. The head-roof
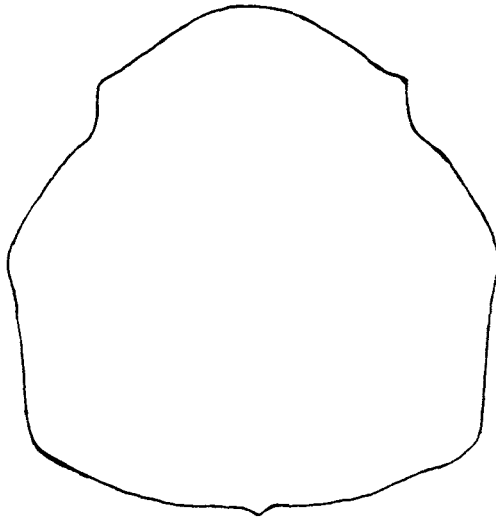
TEXT FIG. 2. *Euryaspis major* Bryant. Restored outline of head-roof. × 1.

measures 67 mm. in length, and indicates a far larger species than any hitherto described. The rostral plate is firmly fused to the remainder of the head-roof, which is never the case in *Anarthraspis*, and the postero-lateral angles are not extended as in the latter genus. In general form the head-

roof agrees with *Euryaspis* except in lateral outline which may be due to faulty preservation. The head is gently vaulted. The rostral region is wide. The orbits are placed well forward. The sensory canals are not preserved in this specimen, and all of the plates are solidly fused, with no outlines evident. The ornamentation consists of minute stellate tubercles closely arranged and evenly spaced.

The comparatively great size of this head-roof nearly twice that of any other known specimen referable to *Euryaspis*, to say nothing of the apparent difference in form, distinguishes *Euryaspis major* from the other species of the genus.

Genus *Ptychaspis* n. gen.

Small forms at present known only by the median dorsal plate. This is elongate, widest in the front part and somewhat constricted in the middle. The superficial sculpture consists of coarse, rounded ridges, often broken up into obtuse tubercles. These radiate towards the periphery of the plate from the centre of ossification.

Ptychaspis arctatus n. sp.

Pl. X, Fig. 2

Type: A median dorsal plate in red limestone (No. 13874).

The single plate upon which this species is founded is entire and is preserved in counterpart. The bone is exceedingly thin. The plate measures 46 mm. in length. Its greatest width is 31 mm. The anterior end is not emarginate but terminates in a blunt median lobe, in this respect resembling *Arctaspis*. The posterior end is gradually drawn out to a median point. The plate is gently arched from side to side and in a lesser degree from front to rear. The greatest vaulting is somewhat in advance of the middle of the plate. The widest portion of the plate is near the anterior end. The antero-lateral angles are rounded. In mid-length the lateral margins are concave.

I believe I can state with some certainty that there was

no longitudinal median keel on the visceral surface of the plate. Although that surface is not exposed, the test is so thin that a keel would be perceptible, if present.

As described above, the ornamentation consists of rounded ridges and tubercles, greatly varying in size. These are not arranged concentrically, but radiate from a point in the median line of the plate which seems to have been the centre of ossification. This sculpture strikingly resembles that in some species of *Holonema*.

It is at once apparent that we have here an Acanthaspid differing quite radically from anything hitherto described. It is probable that further search would disclose other interesting forms, at present known only by material too fragmentary for description. Evidently, the possibilities of Beartooth Butte as a storehouse of the most primitive vertebrates is by no means exhausted.

Body scales among the *Arthrodira* are very rare. They have hitherto been found only in the Acanthaspids, *Phlyctænaspis*, *Lunaspis*, and *Euryaspis*. Those of *Euryaspis brachycephalus* have already been described. On Pl. VI, Fig. 2 I illustrate a detached scale, probably belonging to *Euryaspis cristatus*. It is distinguished by a median spine.

Among the fossils collected last summer (1934) were a number of Eurypterids. These were placed in the hands of Dr. Rudolf Ruedemann for study and he has kindly furnished a description of them, which is appended to this paper.

PLATE I

Cryptaspis ellipticus Bryant. Natural cast of inner surface of dorsal shield with patches of bony tissue adhering. The maxillar brim, eyes, and branchial lobe of the right side are conspicuous. (No. 13844.) $\times 1^1{}_2$

PLATE II

Cryptaspis cordova Bryant. Counterpart of the specimen illustrated on Plate I
Impressions caused by the olfactory capsules, the pineal organ, and the terminal lobe
are shown. The left branchial plate is lying somewhat behind its natural position
(No. 13844A.) $\times 1\frac{1}{2}$

PLATE III

Crypraspi. ellipticus Bryant. View of front end of specimen illustrated on Plate I, enlarged, showing maxillar brim and eyes. $\times 4^1{}_2$.

PLATE IV

Cyrtaspis ellipticus Bryant

FIG. 1. Front half of ventral shield in visceral view. (No 13850) X 1¹⁵.

FIG. 2. Posterior half of specimen illustrated in Plate I, showing branchial openings and impression caused by the hind brain or nerve cord. X 2¹⁵.
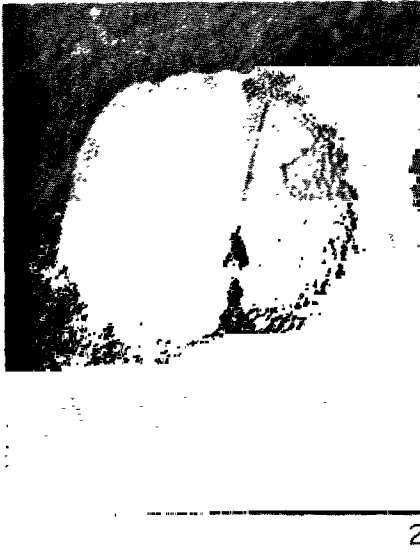
PLATE V

Cryptaspis ellipticus Bryant. Natural cast of front half of dorsal shield in visceral view. The specimen shows impressions caused by the branchial organs, the pineal macula, and the semicircular canals. Certain sensory canals are also evident. (No. 13845.) Ca. × 2.

PLATE VI
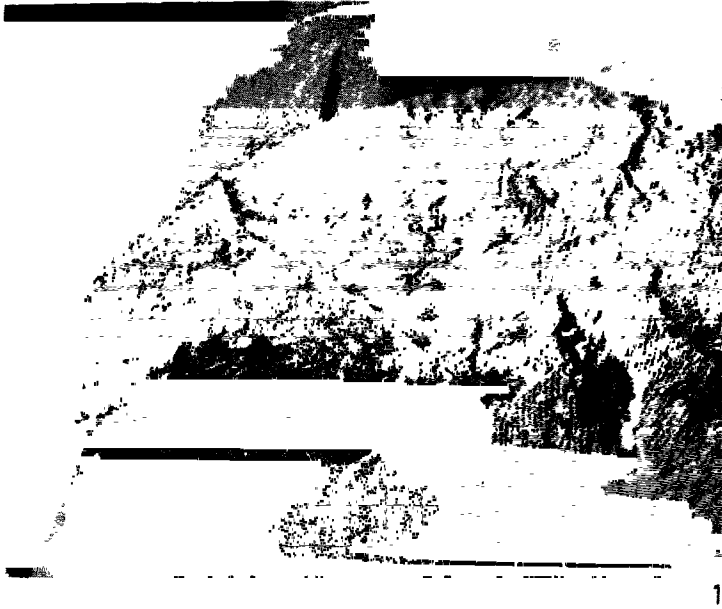
1

2

3

Fig. 1. Front end of specimen illustrated on Plate V, showing tooth-like termi-
nations of dentine ridges at the maxillary border. These may have been functional
to some extent. Ca × 4.

Fig. 2. *Luryaspis cristatus* Bryant. Body scale showing median thorn-like
process. (No. 13878.) × 4.

Fig. 3. Innominate plate bearing peculiar markings. (No. 14177) × 1½.

PLATE VII

Cryptaspis flabelliformis Bryant.   Ventral shield   No. 13888.   Ca. $\times 1\frac{1}{8}$.

PLATE VIII

Fig. 1 *Cyrtaspis* sp. *lyoni* Bryant (?) Right branchial plate. (No. 13815) × 1⅓

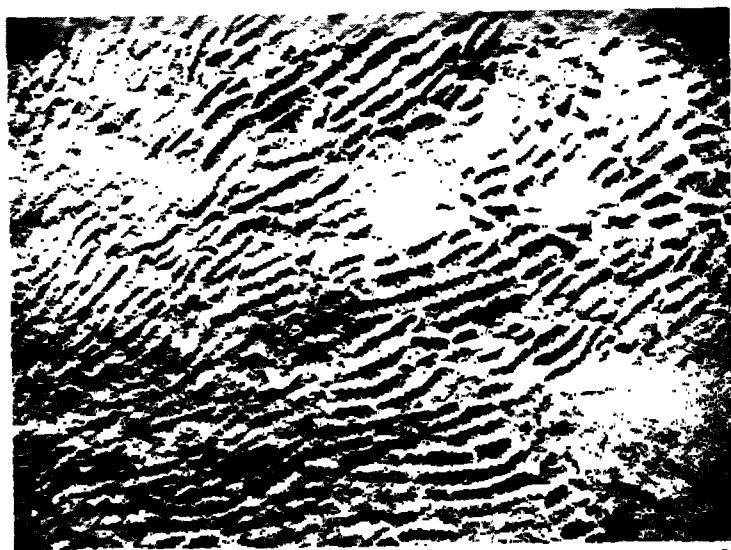Fig. 2 *Cyrtaspis* sp. Branchial plate, showing areas of overlap. (No. 14185) × 2.

Fig. 3 *Cyrtaspis* sp. Branchial plate. (No. 14184) × 1¼.

Fig. 4 *Cyrtaspis* sp. Detached plate of unknown position and function. (No. 13802) × 1½

PLATE IX

1

2

FIG. 1. *Cardip*... *offengus* Bryant Portion of dorsal shield, showing left branchial sinus (No 14182) × 2.

FIG. 2. *Cardipetis* sp. Impressions caused by the superficial sculpture, showing that the dentine ridges are laterally crimped. (No 14181) C2. × 2.

PLATE X

FIG. 1. *Protaspis backeri* Bryant. Juvenile median dorsal plate showing sensory canals. (No. 13883.) $\times 1^1{}_2$

FIG. 2. *Psychaspis cariaeus* Bryant. Median dorsal plate in dorsal view, showing ornamentation (No. 13874) $\times 1^1{}_2$

FIG. 3. *Protaspis backeri* Bryant. Ridge scale detached from the body. (No. 13851.) $\times 1^3{}_4$
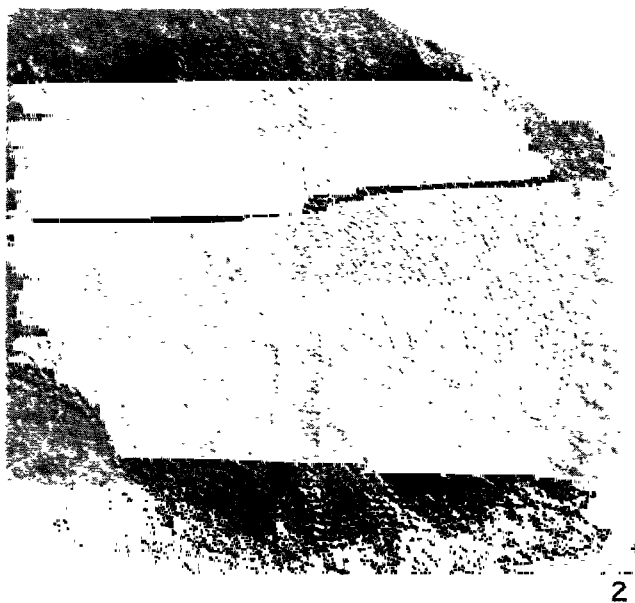
PLATE XI

FIG. 1. *Protaspis bucca* Bryant. A fragment of the body squamation, showing greatly enlarged dorsal and ventral ridge scales. (No. 13885.) × 2

FIG. 2. *Cyraspis ovatus* Bryant. Median dorsal plate of a juvenile individual showing arrangement of the sensory canals. (No. 13873.) × 4

PLATE XII

PLATE XIII

Proaspis backeri Bryant. Dorsal and ventral shields of an individual in natural association. (No. 13801.) × 1⅓

PLATE XXV

Prosarpis ampla. Bryant. Dorsal shield in visceral view, showing one of the cornual plates and the supposed position of the branchial opening (No. 13864) × 3/4.

PLATE XV

Protaspis brevirostris Bryant. Nearly complete and little crushed dorsal shield.
Certain sensory canals shown by dotted lines. (No. 13859.) × 1.

PLATE XVI

Cyraspis oculus Bryant. Complete dorsal shield, crushed nearly flat   No 1580.
× 4.
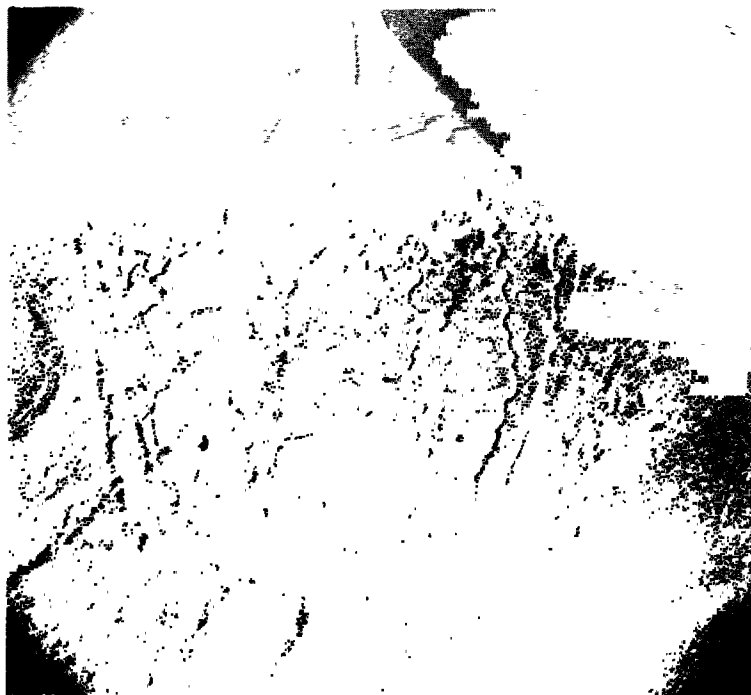
PLATE XVII

FIG. 1.   Innominate plate with peculiar markings.   (No. 14180.)   × 2.
FIG 2.   Innominate plate.   The upper surface has been destroyed, exposing a system of tubes and nodes throughout the interior   (No. 14179)   × 1½.

PLATE XVIII

1

2

Fig. 1   *Euryaspis major* Bryant   Head-roof.   (No. 14183.)   × 1.
Fig. 2.   *Euryaspis cristata* (?) Bryant   Head-roof.   Specimen is preserved in counterpart.   (No. 13891A.)   × 2⅓

APPENDIX

THE EURYPTERIDS OF BEARTOOTH BUTTE, WYOMING

RUDOLF RUEDEMANN

LAST year the writer published a short note on the Eurypterids of Beartooth Butte, Wyoming, that was appended to William L. Bryant's Parts II and III of the "Fish Fauna of Beartooth Butte," published in the *Proceedings of the American Philosophical Society*, Vol. LXXIII, No. 3, 1934, pp. 127–162.

The material described in the first note consisted of an incomplete ventral side of a cephalothorax and abdomen, a posterior margin of a telson and a fragmentary coxal joint of a swimming leg. All of these were referred to a new species of *Pterygotus* which was described as *Pterygotus princetonii* (op. cit., pp. 163–167).

The Princeton expedition of 1934 obtained a somewhat larger collection. The largest of the specimens proves to be the counterpart of the one of the first collection showing the ventral side. Others show the upper side of the carapace with the eyes and fragments of the swimming leg of the same species. A third group consists of the body of a new species of *Eurypterus*, with counterpart. Besides, Mr. Bryant also recognized (letter of Sept. 21, 1934) as a rather poorly preserved, much wrinkled segment of a large Eurypterid, a specimen which before (Pt. II, p. 151) had been noted as the integument of most of the trunk of an unknown fish and illustrated as such on Pl. XXI. The scales indicate it to be a piece of a segment of a large Pterygotus.

Strobilopterus n. gen.

(Etymology: strobilos pine-cone, pteron wing)

The Eurypterid, *Pterygotus princetonii*, was referred by the writer to the genus *Pterygotus* mainly because of the form of

the telson associated with it, the form of the swimming leg as far as then known, and the sculpture of the segments, consisting of flat crescent scales.   It was then recognized that the form, while in its general outline a *Pterygotus*, had a rather broad body and relatively large swimming legs.

The new material, on one hand, has brought out more distinct *Pterygotus* features and, on the other, also definite divergent characters which require its recognition as a new genus.

The characters that agree with *Pterygotus* are: (1) The general outline, (2) the form of the telson, (3) the position and shape of the lateral eyes, (4) the facets of the lateral eyes, (5) the form of the metastoma, and (6) the sculpture of the segments.

The differing characters are: (1) The outline of the carapace, (2) the segmentation of the swimming leg, (3) the form of the opercular appendage.

The following characters of critical importance are as yet unknown, (1) the form and size of the chelicerae, (2) the form of the walking legs, (3) the last postabdominal segment.

The genus may therefore be defined as follows: Outline of body generally as in *Pterygotus* (*i.e. anglicus*) and ending in a broad, obovate telson; lateral eyes marginal, situated in the antero-lateral corners, provided with facets; metastoma elongate-cordate; sculpture of carapace consisting of fine round tubercles, that of the segments, of flat crescentic to linear scales.

The characters in which it differs from *Pterygotus* are the round, semi-elliptic outline and relative shortness of the carapace, resembling that of *Eurypterus;* the segmentation of the swimming leg, which is very unusual and agrees with that of the genus *Dolichopterus,* and the ovipositor which is very unlike that of *Pterygotus* and possesses a character of its own, different from that of other genera.   The swimming leg is not only much broader than that of *Pterygotus*, but also the seventh segment is divided into two segments by a transversal suture, thus producing a nine-segmented swimming leg as in

Dolichopterus (see Mem. 11, Pl. 41),[1] but these segments are also separated into auxiliary lobes again, as in *Dolichopterus* (see Text Figs. 3–5). The opercular appendage is characterized by its great length in distinction to the short organ seen in *Pterygotus* (see op. cit. Pl. 68), but again comparable to that of *Dolichopterus*, though of different composition, its principal distinction being the two long semi-cylindric sheets, opening along the ventral median line. No such structure has been seen in other Eurypterids.

The following characters are still unknown and leave the relationships of the genus somewhat uncertain: The cheliceræ, whether enormously developed as in *Pterygotus* or minute organs as in the other genera: the form of the walking legs which in *Pterygotus* are slender and relatively short and of heavier build in most other genera as in *Eurypterus;* and the form of the last postabdominal segment which in *Pterygotus* is broadened in transition to the telson plate.

The chelicerae and the walking legs have been added to the restorations, Text Figs. 6 and 7, from *Pterygotus*. Their form is however conjectural.

Since the genus, as here conceived, is different from both *Pterygotus* and *Dolichopterus*, but combines certain characters of both of them, it is necessary to distinguish this new type by a separate name. The name *Strobilopterus* (from the shape of the swimming legs, which suggest the scales of pine-cones) is therefore here proposed.

<center>*Strobilopterus princetonii* Ruedemann</center>

<center>Plates I–III; Text Figs. 1–8</center>

*Pterygotus princetonii* Ruedemann. Proc. Amer. Phil. Soc., Vol. LXXIII, No. 3, 1934, P. 163, Pls. I–III, Text Figs. 1–3.

Holotype: No. 13743 Princeton University Paleontological Museum. Counterpart of holotype: No. 13743-A ibidem. *Plesiotypes*, Nos. 13853, 13853-A, 13855.

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[1] Clarke, J. M. and Ruedemann, Rudolf, "The Eurypterida of New York," Memoir 14. New York State Museum. 1912.

The counterpart of the holotype and the additional plesiotypes or hypotypes here figured. permit a more correct description of the swimming leg and opercular appendage and show the location and form of the lateral eyes, the median eyes and the metastoma.
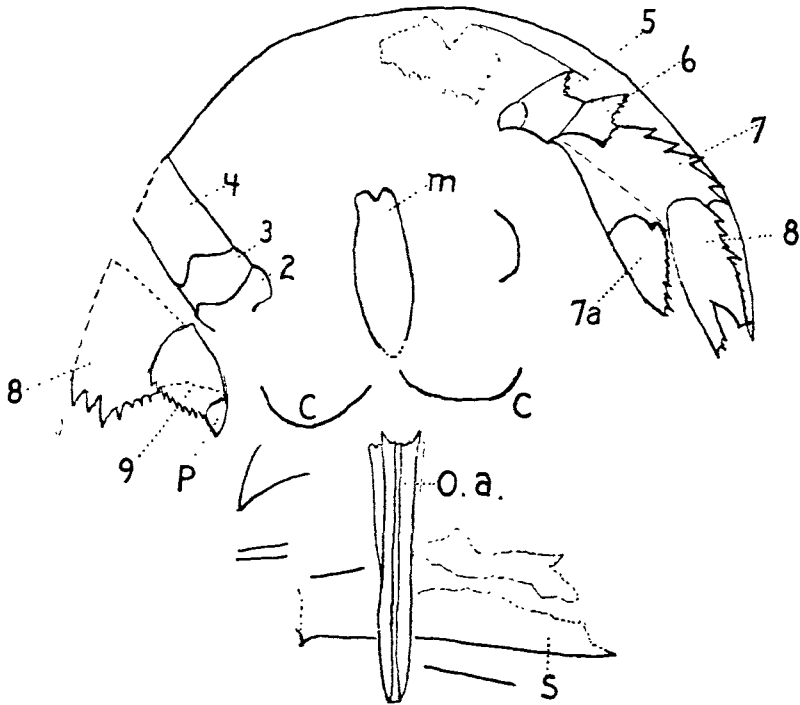
TEXT FIG. 1. *Strobilopterus princetoni* Ruedemann. Outline of Pl. I, showing on right, left swimming leg with segments 5, 6, 7, 7a, 8; on left, segments 2, 3, 4, portion of segment 8 and segment 9 with pallette (p) of right swimming leg. M = metastoma. S = posterior margins of coxae. O. A. = opercular appendage. X 1.

The *lateral eyes* are submarginal, located in the antero-lateral corners. or about half way between the frontal and posterior margins. They are elliptic in outline, prominent, more than one-fourth the length of the carapace and lacking an elevated inner eye-lid. The facets are fairly large, numbering three in 1 mm. The *median eyes* are placed near the connecting middle line of the lateral eyes.
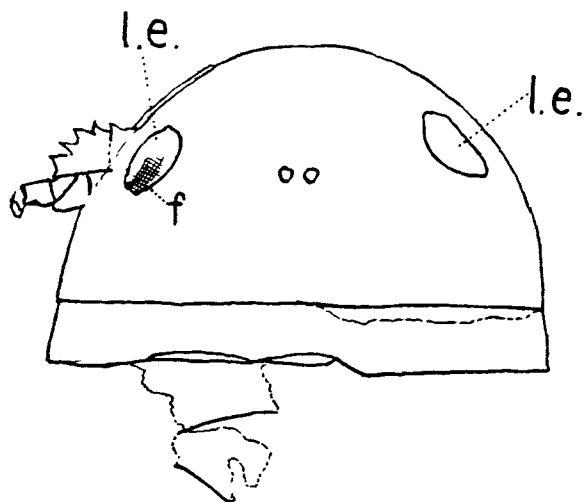
Text Fig. 2. *Strobilopterus princetonii* Ruedemann. Outline of Pl. II, Fig. 1, showing lateral eyes (l.e.) with facets on left side. × 1.
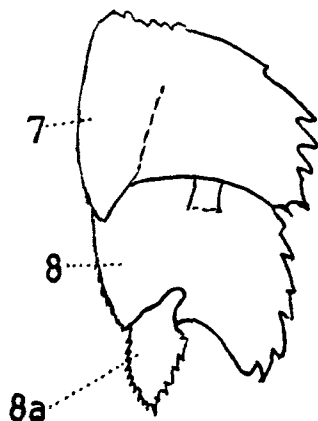
Text Fig. 3. *Strobilopterus princetonii* Ruedemann. Outline of Pl. II, Fig. 2. Segments 7, 8, 8a of swimming leg. × 1.

The *metastoma* is elongate cordate in outline; its greatest width which is about the middle, is approximately one-third the length, but probably was originally somewhat greater as the plate is laterally compressed to some extent.

Opercular appendage. The type specimen, described in 1934, retained only a short fragment of the middle of the opercular appendage, which led to a wrong restoration (see ibid. Fig. 2). Besides this, a semi-circular node at the posterior margin of the third sternite is shown, which is of unknown function. The counterpart of the holotype, here reproduced in Pl. I, is much better preserved and among others
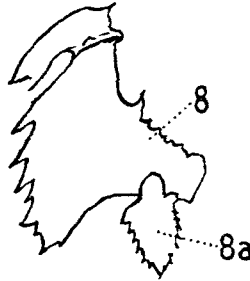
TEXT FIG. 4. Portion of counterpart. × 1.
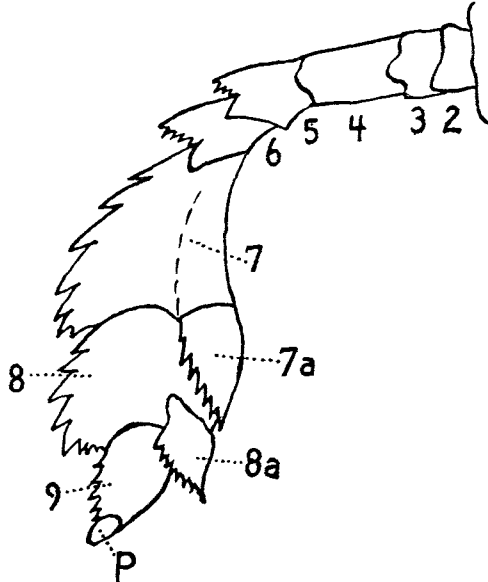
TEXT FIG. 5. *Strobilopterus princetonii* Ruedemann. Diagram of swimming leg, save the coxal joint, seen from below. × 1.

retains the entire opercular appendage save the basal plates. This proves to be of the larger type which has been currently identified as the ovipositor of the female, but is termed appendage of type A by Störmer [1] as doubt has arisen as to the true function of this organ.   The base is represented by
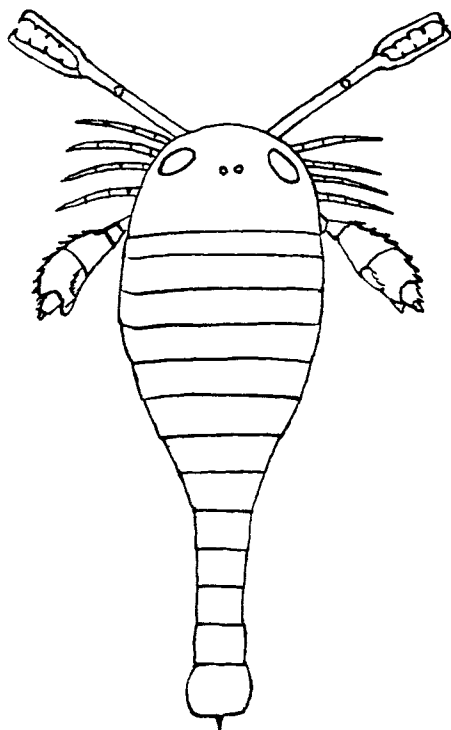
Text Fig. 6.   *Strobilopterus princetonii* Ruedemann.   Restoration of dorsal side.

two divergent sutures, beyond which two triangular basal plates may have been present.   The appendage consists of two narrow paired sheaths, that widen slightly at the distal end and terminate bluntly.   They leave open between them a fairly wide slit, extending their whole length.   They seem to have been continuous on the inner side.   The tube is flanked

[1] Störmer, Leif, "Merostomata from the Downtonian Sandstone of Ringerike, Norway."   Skrifter Utgitt av Det Norske Videnskaps-Akademi i Oslo, 1.   Matem-Naturvid. Klasse, 1933.   No. 10, P. 44.

on both sides of the proximal half by concave distally tapering narrow wings or flanges.

This opercular appendage, while in outline similar to that of type A of *Pterygotus* (see Störmer, Fig. 19), lacks the transverse middle suture and possesses the median slit, there only
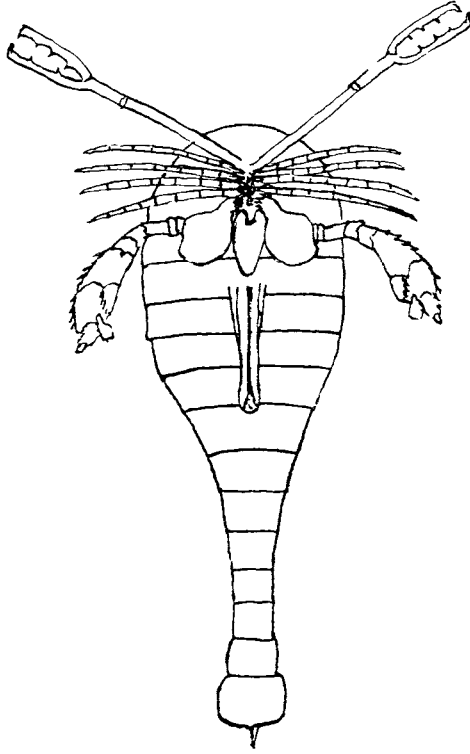
Text Fig. 7.   *Strobilopterus princetonii* Ruedemann.   Restoration of ventral side.

suggested by a suture.   It is comparable in structure to the opercular appendages of *Hughmilleria norvegica* Kiaer (see Störmer, Fig. 30), and of *Mixopterus Kiaeri* (see ibid. Fig. 38) both of which show a median suture partly open.

Swimming leg.—The most striking organ of this Eurypterid is the swimming leg.   It is of larger size than in the congeners and as its extension, by accessory lobes indicates, was quite probably of great importance.   The coxa is known only from

its posterior margin.   Judging from this it was not of the
great relative size as in *Pterygotus buffaloensis* and other
species where it extended to the lateral margin of the carapace.
The second and third segments are subannular and short, as
in the congeners; the fourth, however, is prolonged into a
tubular organ of about twice the length of the preceding
segments.   It has this character in common with *Dolichopterus*.
The fifth and sixth segments also differ from those of *Pterygotus*
and other Eurypterids by their peculiar distal overlapping
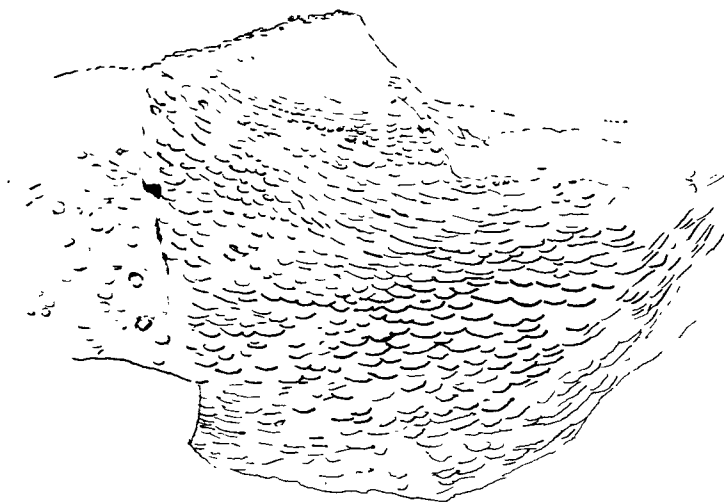
TEXT FIG. 8.   *Strobilopterus princetonii* Ruedemann.   Outline of Fig. of Pl. III.   × 1.

lobed extensions, provided with dentate margins.   The
undivided seventh segment of *Pterygotus* and of the majority
of the Eurypterids is here divided by a transverse suture into
two segments, as in *Dolichopterus*, each bearing an auxiliary
lobe (7a and 8a of Text Fig. 5) on the inner side.   All these
lobes bear sharp spines on the outer margin.   The seventh
and eighth segments constitute the principal oar-plate of the
swimming leg.   Finally, the ninth segment, which corresponds
to the oar-plate (eighth segment) of *Eurypterus*, *Eusarcus*, and
Pterygotus, is reduced in *Strobilopterus* to a small plate but one-
fourth the size of the preceding one.   It bears a small, oval

pallette which is lacking in the similar swimming leg of *Dolichopterus*.

The sculpture of the carapace consists of small but prominent tubercles on the carapace and first tergites; it changes posteriorly into crescent and finally linear scales.

The position of the tergite, originally referred to the fishes by Bryant and here reproduced in Text Fig. 8, may represent either a different species of *Pterygotus* or belong to a much larger specimen of *Strobilopterus princetonii* than is indicated by the other remains. The sculpture of the tergite which shows a tendency to change from crescent to linear scales is well comparable to that of *Strobilopterus princetonii*, and the fossil may be considered as indicating a size at least three times that of the holotype, a view that is supported by the large coxa and posterior margin of the telson plate figured in the first article. It is, therefore probable that this form reached a length of three feet and more.

Eurypterus latus nov.

Pl. IV; Text Figs. 9–12

Description: *Body* of small size, broadly ovate-lanceolate in form, about three times as long as wide, relatively wide in
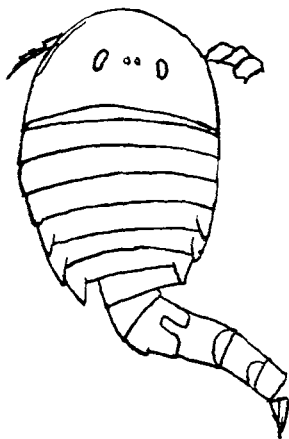
TEXT FIG. 9. *Eurypterus latus* nov. Outline of Pl. IV, Fig. 1. Holotype. × 1.
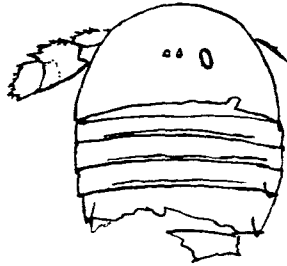
TEXT FIG. 10.   *Eurypterus latus.*   Outline of Pl. IV, Fig. 2, to show more distinctly the ocelli and swimming leg.   × 1.

TEXT FIG. 11.   *Eurypterus latus* nov.   Camera drawing of walking leg of holotype. × 8.

front and broadest at one-fourth of its length, but little convex.

Cephalothorax is relatively small, the carapace occupying but one-fifth of the length of the body. The latter is approximately semicircular in outline, its length about half its width, its lateral margins forming a continuously rounded curve with the anterior margin, that shows but a faint suggestion of an antero-lateral angle. The posterior margin is broadly concave, the post-lateral angle subrectangular. There are traces of a narrow flat marginal rim. The compound eyes are small, kidney-shaped and prominent, situated

in the middle, as far apart as they are distant from the lateral margin.   *Ocelli* are small and situated on a line connecting the frontal margins of the lateral eyes.

The *preabdomen* is wider than long, its proportions as 7 : 5; it is widest at the second tergite, contracting rapidly
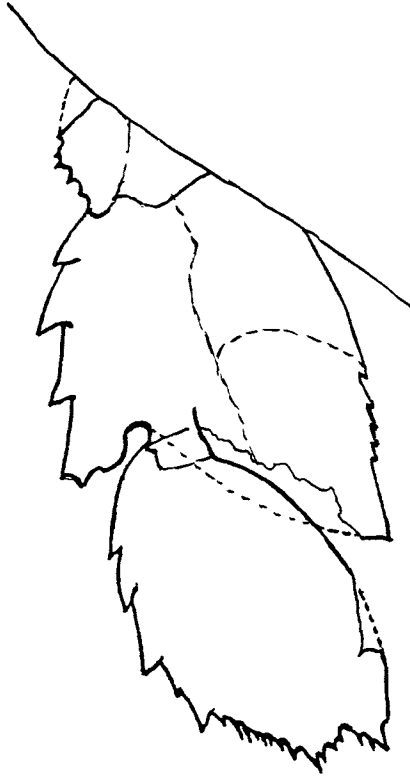
TEXT FIG. 12.   *Eurypterus latus* nov.   Camera drawing of swimming leg of holotype.
× 8.

to the sixth tergite which is only 3/5 the greatest width. The tergites are narrow and band-like, from seven to three times as wide as long, and slightly arched forward.   The last three bear blunt triangular post-lateral lobes.

The first two *postabdominal segments* are broader than long, but rapidly contracting to 2/7 the maximal width of

the body at the third segment; the third to sixth segments are longer than wide and narrowing to a final width of but 1/7 the maximal width. Only a part of the *telson spine*, which is bent downward, is visible, indicating that it was relatively short and blunt.

Sculpture.—The carapace, tergites and postabdominal segments are provided with a surface sculpture of fine tubercles.

Measurements.—Total length is 86.5 + mm; greatest width 34 mm., basal width of carapace 33 mm., length 17 mm.; length of lateral eyes 35 mm.; length of tergite 5 mm.; width of last tergite 21 mm.; width of last postabdominal segment 5 mm.

Appendages.—Of the appendages only a thin walking leg, probably the third, projecting 11 mm. beyond the carapace and showing four segments with finely dentate distal margins is shown (see Text Fig. 11). Also the last three segments of a broad, short swimming leg are seen, projecting 17 mm. and 11 mm. wide and furnished with distinct teeth at the outer margin. No terminal pallette is present.

Remarks.—Compared with other species of *Eurypterus*, this form distinctly differs in its broad form, notably the broad carapace and preabdomen and the sharply set-off narrow postabdomen, short telson spine and short, broad, swimming legs. Its outline recalls that of the Silurian *E. ranilarva* Clarke and Reudemann, from the Kokomo limestone, but it is still more contracted in the postabdominal region.

PLATE I

Strobilopterus princetonii Ruedemann.
Counterpart of holotype. (No. 13743A Prin. Univ. Pal. Mus.) Found by Dr. Erling Dorf, 1934. × 1.

PLATE II

Strobilopterus princetonii Ruedemann.

FIG 1. Carapace retaining lateral eyes. (No 13855) Plesiotype ×1
FIG 2. Fragment of swimming leg, showing seventh and eighth segments (No. 13853) Plesiotype. ×1
FIG. 3 Portion of counterpart of Fig. 2. (No. 13853A.) Plesiotype. ×1.

PLATE III

Strobilopterus princetonii Ruedemann

Fragment of tergite of large individual, showing the characteristic sculpture. (No. 13661.) × 1.

PLATE IV

2

Euryptera latus nov.

FIG. 1. Holotype. (No. 13854) Found by Dr. Erling Dorf. 1934. × 1.
FIG. 2 Counterpart of holotype. (No. 13854A)

SECOND CONTRIBUTION TO THE OSTEOLOGY AND AFFINITIES OF THE PALEOCENE AMBLYPOD TITANOIDES

BRYAN PATTERSON

During the summer of 1933 the Field Museum continued the programme of field work in western Colorado which was begun in 1932. A party consisting of Mr. James H. Quinn, Mr. Clayton A. Quinn and myself spent some three months in the vicinity of Plateau Valley and De Beque in Mesa County, and Rifle in Garfield County. During this time an excellent series of *Titanoides* was obtained, including three nearly complete skeletons which were found mingled together in a single spot. In addition, a few small Paleocene and some lower Eocene mammals were collected. The Paleocene specimens indicate either Clark Fork or Tiffany age for the *T. faberi* horizon. Since the *Titanoides* material is not yet completely prepared, the present communication is confined to a preliminary description of such parts of the skeleton as were missing or poorly represented in the 1932 collection.

I wish to express sincere thanks to my associates on the expedition, and to Mr. Edwin B. Faber and Mr. H. L. Wohlfort of Grand Junction, Mr. J. Elvin Harris and Mr. Douglas Harris of Mesa, and Mr. Charles Deardorf of Silt, for the many kindnesses they showed to the party. Mr. Jack Stoner of De Beque discovered and kindly directed me to the place at which the three *Titanoides* skeletons were collected.. The preparation of the collection has been skilfully executed by Mr. James H. Quinn. The drawings are the work of Mr. Carl F. Gronemann, Staff Artist, Field Museum.

Order AMBLYPODA Cope
Family Pantolambdidæ Cope
Subfamily Titanoidinæ Patterson
Genus *Titanoides* Gidley 1917

The following characters may be added to the generic diagnoses that have been given in previous publications: Premaxillaries greatly reduced, ascending rami not reaching nasals;[1] caudal vertebræ with chevrons; centrale relatively very large.

Titanoides faberi Patterson 1933

T. faberi Patterson 1933, *Amer. Jour. Sci.*, (5), **25**, 417; 1934, this journal, **73**, 71.

Horizon: Upper Paleocene.

The following description has been taken mainly from the three articulated skeletons; these bear the Field Museum numbers P14944, P14945, and P14946.

The specimens show a certain amount of variation, but at the present time I am not prepared to regard this as anything more than individual. I hope to deal with this question more fully at another time.

Dentition.—The dental formula is $I\frac{3-2}{3}$, $C\frac{1}{1}$, $P\frac{4}{4}$, $M\frac{3}{3}$.

The only portions of the permanent dentition as yet undescribed are the upper incisors, canine, and P^{2-4}. The incisors increase in size from ^{1} to ^{3}. The first pair, when present, are very small, circular in outline, bear lateral ridges, and have a very weak, discontinuous internal cingulum. They are lacking on P14944, a fact which indicates that they are vestigial teeth that would have been eliminated if the titanoidine phylum had survived for a longer time. The second have stronger lateral ridges, on one specimen they almost form cusps, and the apices are slightly inclined laterally. The third incisors are very large, conical, and with moderately developed lateral ridges. The canine is about one third larger than I^{3} and is very similar to it in structure.

Premolars $^{2-4}$ show a steady increase in size posteriorly and are very similar in structure to those of *Pantolambda*. They are simple, bicrescentic teeth with the higher external

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[1] In an earlier paper (Patterson, 1934, p. 79) it was erroneously stated that the ascending rami were in contact with the nasals.

crescent composed of the parametacone [1] and the parastyle and metastyle crests; the internal crescent consists of the protocone and the anterior and posterior cingula. On P^{2-3} the metastyles and metastyle crests exceed the parastyle and parastyle crests in size and length; on P^4 the two are approximately equal. On P^{3-4} there is an incipient mesostyle above the parametacone.

The rest of the dentition has been described previously, but some notes may be added here. The curvature of the posterior face of the upper molars is variable. In the immature specimen previously figured (Patterson, 1934, fig. 1), the transverse axis of M^3 is in transverse alignment; in adult specimens this axis is in postero-internal alignment. The cuspules in the talonid basins of the lower premolars and molars are variable in development, on some teeth they are not developed at all. The value of this feature as a specific character for *T. faberi* is accordingly diminished.

Skull (Fig. 1).—The skull is small in comparison with the size of the skeleton and is remarkable for the extreme shortness of the facial region, a feature which is directly due to the reduction of the premaxillaries. These bones project but little in advance of the canines, are very loosely attached to the maxillaries, and do not meet in a median suture, but are merely in contact. The face is considerably deeper than that of the skull of *Pantolambda bathmodon* figured by Osborn (1898, p. 181, fig. 8). The nasals extend posteriorly above the orbits, being greatly expanded transversely at this point. The infraorbital foramen is very large, as in *Pantolambda*. The pars facialis of the lachrymal is rectangular and the tubercle is prominent; the foramen is situated within the orbit. The orbit is relatively very small; there are strong temporal ridges which terminate in very stout postorbital processes. The anterior root of the strong, fairly deep zygomatic arch is in the primitive position above M^{1-2}. The

[1] For descriptive purposes the same nomenclature is used for cusps occupying the same topographic position on the premolars and molars. It is recognized, however, (Gregory, 1934) that these cusps may have had different developmental histories in the two series.

cranial region is broad and very low, somewhat lower, even, than that of the skull of *P. bathmodon* already alluded to. There is a well developed sagittal crest. The auditory channel is very wide. The occiput is low and rounded and the condyles project strongly in the posterior direction. The side walls of the posterior nares are extremely long, extending posteriorly almost to the basioccipital-basisphenoid suture. The basisphenoid bears a median ridge which seems to be continuous anteriorly with the vomer. The latter bone apparently meets the palatines at the posterior narial opening and thus divides the choanæ. The periotics are widely exposed and send forward curious heavy processes, which extend anteriorly and ventrally on the internal sides of the postglenoid processes.

Increased knowledge of the skull of *Titanoides* has revealed certain differences from the skull of *Pantolambda*, but the fundamental similarity of the two genera in cranial structure is even more firmly established.

Mandible (Fig. 1).—The new material permits the correction of an error in the previous description (Patterson, 1934, p. 80), in which the posterior border of the ramus was represented as being vertical and the angle as extending downwards and slightly backwards. Acutally the angle is extremely well developed and projects posteriorly beyond the condyle.[1] There is a certain amount of variation between the specimens in the shape and slope of the coronoid process, but this is regarded as individual and not specific; the variation shown does not exceed that observed in a series of guanacos, *Lama guanicæ*, from the Province of Santa Cruz, Argentina.

Vertebræ.—There are seven cervicals, almost certainly fifteen dorsals, five lumbars, three sacrals (the third being a pseudosacral), and twenty-one caudals. The neck is very short and the cervical vertebræ, in keeping with the size of the head, are small in comparison with the size of the rest of

[1] In the previously figured mandible the angles were weathered off before or after burial, but the edges were so evenly beveled that the surface appeared to be a natural border.

the skeleton. The dorsals and lumbars have short spines and, as stated previously, increase in size posteriorly. The sacrals (Fig. 4) are very large; the spines of the first and second are completely united on P14944 and partially so on P14945, the third (the pseudosacral) is partially free on P14944 and entirely free on P14945. The metapophyses of the second sacral and of the pseudosacral project freely. The co-ossified transverse processes and ribs of the true sacrals are
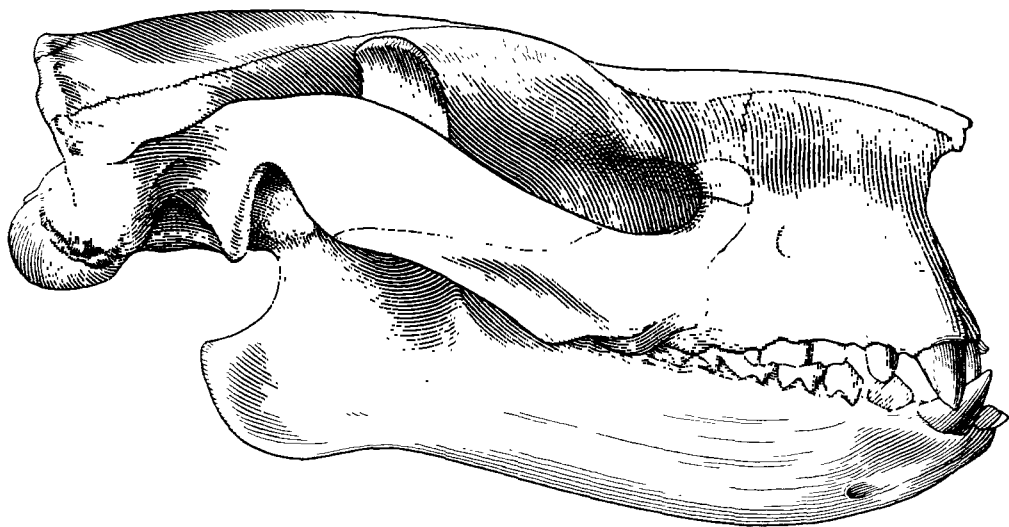
TEXT FIG. 1. *Titanoides faberi.* Skull and mandibles, side view, P14944. $\times \frac{2}{5}$

enormously expanded and are functionally a part of the ilium (see p. 153). The tail is perhaps the most remarkable feature of this peculiar animal: it is very long, extraordinarily massive, and tapers rather rapidly towards the end. The spines of the anterior caudals are very high and the transverse pro-cesses wide. The neural arches are complete down to and including the eleventh caudal. Chevrons are attached to all vertebræ except the last four and possibly the first, and are extremely large anteriorly; including the chevron, the total depth of the third caudal of P14944 is about 270 mm. or nearly eleven inches. The possession of chrevrons by *Tita-noides* constitutes a conspicuous and important distinction from *Pantolambda.*

The presence of *clavicles*, tentatively indicated in the previous paper, is now conclusively proved. The flat expanded end of this bone (Patterson, 1934, p. 81) probably had a ligamentary attachment to the acromion process. An undescribed specimen of *Pantolambda* in the American Museum (A.M. no. 16663) [1] has a portion of the clavicle attached to the scapula, a fact hitherto unrecorded. The scapulæ of the same specimen are incomplete, but the parts preserved show similarities to *Titanoides*. In Osborn's figure (1898, fig. 9, p. 183) the scapula of *Pantolambda* is incorrectly restored after that of *Coryphodon*.

The humerus and radius have already been briefly described. The ulna (Fig. 2) is a stout bone, narrow transversely and very deep antero-posteriorly. In outline and proportions it is similar to that of *Pantolambda*. The axis of the olecranon is continuous with that of the shaft and is not inclined posteriorly, in contrast to that of *Coryphodon*. The semilunar (great sigmoidal) notch is very similar in shape to that of *Coryphodon*, but is not as convex transversely. The mesial surface of the shaft is gently convex, the lateral [2] bears a wide shallow groove bounded posteriorly by a ridge from which the extensor lateralis digitorum probably originated. The region about the distal epiphysis is thickened and rugose; the osseous articulation with the radius is small. The facets for the cuneiform and pisiform are continuous, the former is plane and the latter convex.

The articulations between the humerus, radius, ulna, and manus indicate that in a normal standing pose the elbow was thrust out from the body.

Manus (Fig. 3).—The distal row of carpals, the metacarpals, and the phalanges of digits II–IV have already been briefly described. The material now in hand includes several fore feet, of which the figured specimen is the most complete, and provides an adequate conception of the entire structure.

[1] I am indebted to Dr. Walter Granger and Dr. George Gaylord Simpson for the privilege of examining and commenting upon this specimen.

[2] *I e.* lateral and mesial in relation to the semilunar notch. When the limb is articulated the lateral and mesial sides face almost anteriorly and posteriorly.

The pisiform is a large, irregularly shaped nodule of bone, nearly circular in both the transverse and vertical sections. The cuneiform facet is circular, plane, and faces anteriorly,

TEXT FIG. 2. *Titanoides faberi.* Right radius and ulna, P14945. × ¼.

the articulation for the radius is narrow, transverse, concave, and faces dorsally. The facets are not contiguous. The radial facet is the most dorsal point of the bone and there is no indication of a hook-like process that might extend pos-teriorly. The pisiform of *Titanoides* is therefore very different

from that of *Coryphodon*, which has such a process well developed. The cuneiform is a large bone, irregularly oblong in general outline. The articulation for the unciform is extensive and gently convex. The radial and pisiform facets are well separated, nearly circular, and plane; the radial is the larger of the two. The pisiform facet faces rather more
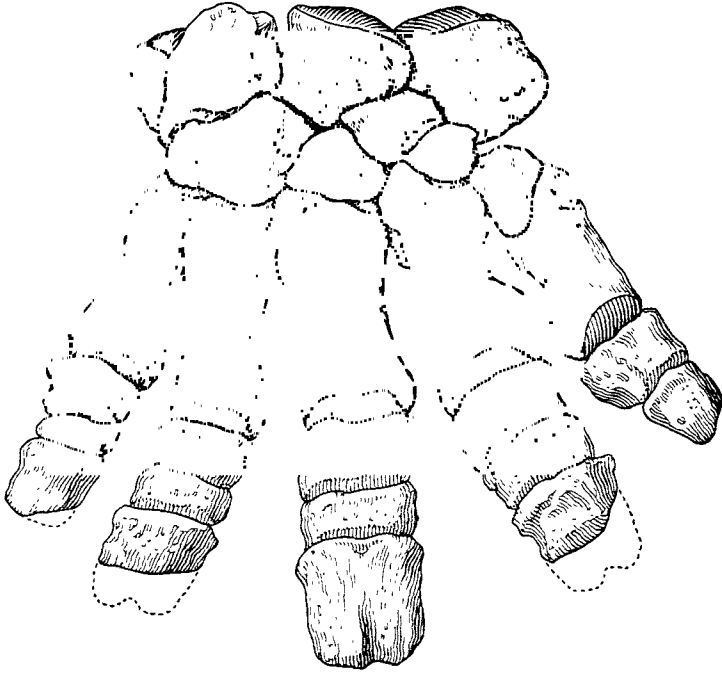
TEXT FIG. 3. *Titanoides faberi.* Right manus, P14945. × ⅓. The trapezium is crushed vertically, if undistorted it would be in contact with the scaphoid.

posteriorly than dorsally, the radial more dorsally than posteriorly. No evidence of an articulation between the cuneiform and Mc V has been found. The lunar is deeper and more wedge shaped than that of *Coryphodon;* the shape, which is similar to that of *Pantolambda,* is due to the presence of a separate centrale which prevented expansion toward the radial side. The facet for the cuneiform is relatively small and confined to the distal portion of the ulnar face of the bone, the lunar articulation is large, while the facets for the magnum

and the centrale are approximately equal in area.   The sca-
phoid is large and irregularly oval in outline.   It articulates
with the centrale, trapezoid, and trapezium, but apparently
not with the lunar.   In the figured specimen the proximal
end of the trapezium is crushed down so that it does not come
into contact with the scaphoid; this defect has not been cor-
rected in the drawing.   The large centrale, which is approxi-
mately equal in size to the trapezoid, is the most striking
feature of the carpus.   The anterior half of the bone is quad-
rangular, the posterior half is narrow transversely, deep
dorso-ventrally, and has an arched dorsal surface.   The
facets for the lunar, scaphoid, magnum and trapezoid are all
large.   On the anterior face the transverse diameter is the
larger; although there is no contact with Mc II, the depth of
the centrale is sufficient to prevent direct articulation between
the magnum and the trapezoid.   The unguals of digits I and
V are relatively small and are not fissured.

The manus as a whole is similar in its breadth, massive-
ness, and proportions to that of *Coryphodon*, a resemblance
in part due to the independent acquisition of size and weight
in the Coryphodontidæ and Titanoidinæ.   The large, fissured
unguals of digits II to IV are exceptions to this general
statement and are distinctive characters of the genus.   In
the structure of the carpus there is a closer resemblance to
the primitive *Pantolambda* than to *Coryphodon*, due chiefly
to the separate centrale.   The relatively larger magnum and
smaller trapezoid are advances from the *Pantolambda* type
and may be regarded as adaptations to meet increasing
weight.   Despite its several modifications, however, the
manus is similar to that of *Pantolambda* in all important
points of structure and was undoubtedly derived from a form
in a similar stage of evolution to the Torrejon genus.

The cuneiform-unciform-lunar and the scaphoid-trape-
zoid-trapezium articulations of *Coryphodon* are similar to
those of *Pantolambda* and *Titanoides*.   The major differences
in carpal structure between *Titanoides* and *Coryphodon* are
caused by the retention of a separate centrale by the former.

It seems probable that the early members of the coryphodont
phylum possessed a foot of the pantolambdid type with a
separate centrale. This bone, important in the titanoidine
phylum, was eliminated in the coryphodontid phylum and its
place filled by the surrounding bones with the result that in
the graviportal *Coryphodon* the lunar is flattened and the
magnum and scaphoid are truncate. This view of the origin
and evolution of the manus of *Coryphodon* from a panto-
lambdid type, while frankly theoretical, is in accord with the
evidence of the dentition and receives strong support from
the tarsus of *Titanoides* (p. 159).

Fore-limb Ratios.—In the preceding paper (Patterson,
1934, p. 93) the ratios of the specimens collected in 1932 were
given. In the table of measurements the maximum lengths
of the limb bones were taken. Professor Gregory, however,
has kindly informed me that the lengths given by Professor
Osborn and himself in Chapter IX of the titanothere mono-
graph were measured "between articular facets as nearly as
practicable at right angles to the general axes of the shaft." [1]
Ratios based on measurements taken from such points neces-
sarily differ from those based on total lengths. In view of
this, the fore-limb of P14902, collected in 1932, was re-
measured. The results are given in the accompanying table,
together with the measurements and ratios of P14945, col-
lected in 1933.

	Humerus	Radius	Radio-humeral ratio	Mc III	Metacarpo-humeral ratio
P14902...	493	341	69	103	21
P14945	408	291	71	94	23

Making due allowance for distortion, inevitable in material
from such an early horizon, the two individuals may be said
to have almost identical ratios, despite the disparity in size
between them. The radio-humeral ratio is as advanced as
that of *Uintatherium;* the metacarpo-humeral ratio is more

[1] Letter of October 29, 1934.

primitive, being intermediate between the ratios of *Panto-lambda* and *Coryphodon*.   *Titanoides* is certainly a graviportal form, but in the fore-limb structure it is not a typical recti-grade according to the definition of Gaudry's term given by Osborn (1929, p. 734).   The genus agrees with this definition in having short, wide feet and short phalanges.   The fore-limb, however, is not straight or post-like but angulate, a feature evidently retained from earlier, ambulatory panto-lambdids.

Pelvis (Fig. 4a and b).—The specimens collected in 1932 revealed that *Titanoides* was a graviportal form, and a large, broad pelvis was therefore to be expected.   Even so, the great size of the first pelvis uncovered in the field in 1933 came as a surprise to the excavators.   The specimen shown
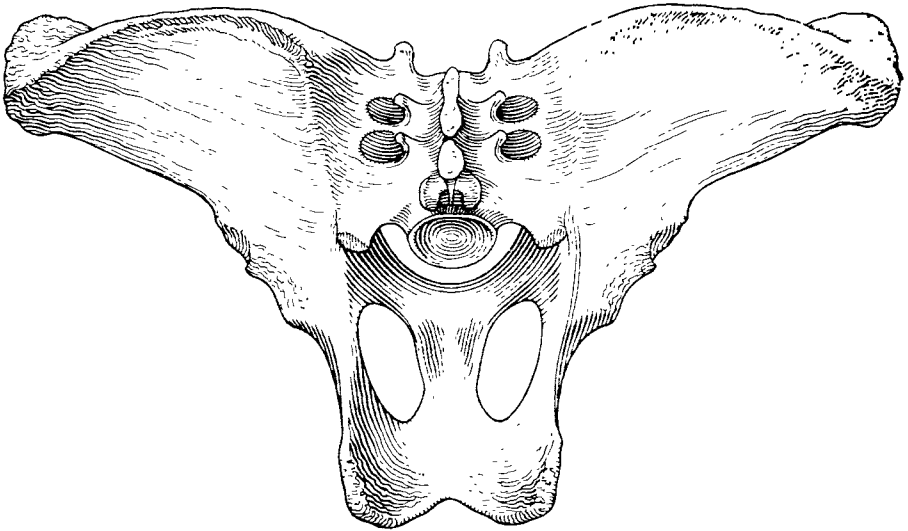
TEXT FIG. 4a.   *Titanoides faberi.*   Pelvis and sacrum, dorsal view, P14944.   × 1⁄5.

in Fig. 4a measures approximately 890 mm., or 35 inches, across the ilia.

The ilium is very short antero-posteriorly and wide trans-versely, as in other heavy-bodied animals.   The supra-iliac border, or crest, is very broad. gently arched. convex through-out its length, and very rugose; it meets the lateral border at

an acute angle. There is no trace of a crista iliaca. There is no tuber sacrale, the place of this structure, which is well developed in graviportal artiodactyls and perissodactyls, being taken by a low, rugose ridge which forms the mesial boundary of the gluteal surface. This ridge, to which the transverse process of the pseudosacral is attached, extends posteriorly into a blunt, flattened process. The ridge, and also a crescent shaped portion of the gluteal surface is formed by the greatly expanded transverse processes and ribs of the true sacral vertebræ. The gluteal surface is therefore composed of two elements—the ilium and the sacrum, a rather unusual condition. The structure of this region is particularly well shown in P14945, a young adult individual (Fig. 4b). Cope and Osborn give no hint of such a development
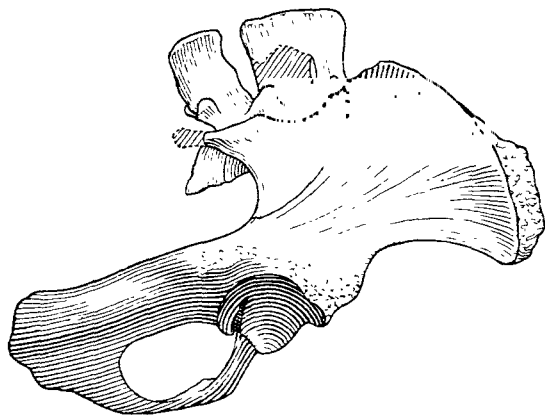
TEXT FIG. 4b. *Titanoides faberi.* Pelvis and sacrum, lateral view, P14945. The suture between the sacrum and the ilium is clearly shown. The epiphyses of the ilium and ischium are lacking.

in either *Coryphodon* or *Pantolambda*. The figures and description given by Marsh in his monograph on the Dinocerata clearly show that there is no comparable development in the uintatheres. The iliac peduncle is extremely short and very broad. The presence of a rugose, plate-like process extending out in a right angle from the antero-internal corner of the ilium is a striking feature. This plate, which seems to be in part an outgrowth of the ventral surface and in part epi-

physial, does not affect the dorsal contour of the supra-iliac crest.   Since there is no comparable development in existing mammals the function of the process is somewhat obscure. It seems likely, however, that the lateral side provided attachment for the origin of the tensor fasciæ femoris.   The anterior side probably provided attachment for parts of the origins of the obliquus abdominis externus and internus.   The mesial border of the gluteal surface is separated from the sacral spines by a considerable space.   The enormous size of the tail clearly indicates that this space was occupied by the very large extensor caudæ medialis and lateralis and the abductor caudæ.   The projecting metapophyses of the sacral vertebræ furnished additional points of origin for these muscles.

The acetabulum is nearly circular, deep, and has projecting borders.   The ligamentous sulcus is very small and narrow, but considerable depth is imparted to it in its posterior portion by the projecting acetabular borders of the ischium and pubis.

The ischium is relatively long.   The supraobturator bar is fairly deep dorso-ventrally, but narrow transversely; it is flat mesially and gently convex laterally.   There is no distinct ischial tuberosity, but a low rugose area extends from the supraobturator bar to the pubic symphysis.

The pubis is fairly broad, the symphysis is long, and the preobturator bar oval in cross section.   The obturator (thyroid) foramen is large and oval.   The pelvic aperture is wide and shallow.

Cope (1884, pl. 29c, fig. 7) has figured an incomplete ilium of *Pantolambda* which, although much narrower than that of *Titanoides*, indicates approximately the structure and proportions of the ancestral titanoidine ilium.   The Titanoidinæ evidently passed directly from ambulatory to graviportal locomotion, which accounts for the lack of the tuber coxæ and the crista iliaca, structures that may be regarded as primarily cursorial adaptations.   Development of a tuber sacrale may have been inhibited by the large size of the dorsal

caudal muscles.   In comparison with the pelvis of *Coryphodon lobatus* (Osborn, 1898, fig. 24, p. 206), the pelvis of *Titanoides* has wider and narrower ilia, and longer ischia, pubes and pubic symphysis.
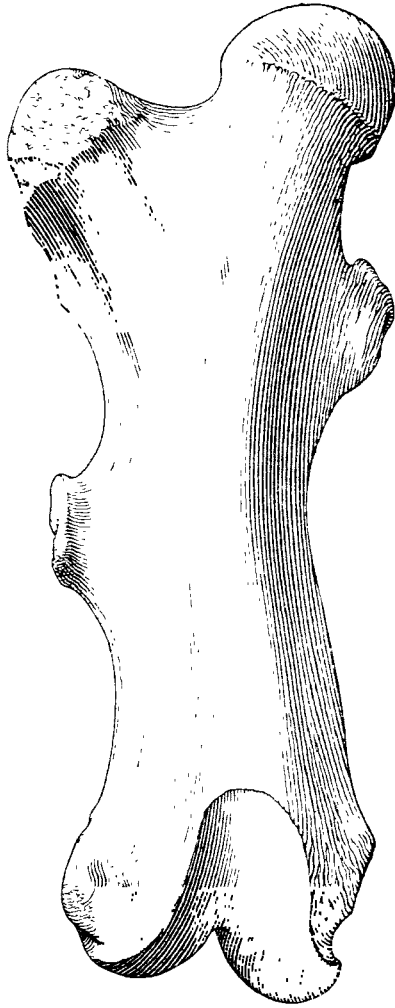
TEXT FIG. 5.   *Titanoides faberi.*   Right femur, P14944.   × ¼.

Femur (Fig. 5).—The femur is long in comparison with the tibia; the shaft is wide, flat posteriorly and rounded anteriorly. There is no pit for the ligamentum teres in the head.   The

great trochanter is very massive and rugose and is somewhat lower than the head. The second and third trochanters are large; the third is situated about half-way down the shaft. The rotular surface is very slightly concave, roughly triangular in outline and continuous distally with the large condyles. The width of the shaft and its flatness posteriorly, the low great trochanter, the large third trochanter and the length of the bone compared with that of the tibia are all graviportal characters. The differences from the femur of *Pantolambda* (Osborn, 1898, fig. 11), such as the straighter shaft, larger and lower great and third trochanters, are due to the acquisition of weight by *Titanoides*. In comparison with *Coryphodon* (Cope, 1884, pl. 44b, fig. 4, pl. 44g, fig. 2), *Titanoides* has a stouter femur with larger trochanters.

The tibia and fibula have been described previously.

The *pes* (Fig. 6).—The astragalus, calcaneum, navicular and cuboid have already been figured and briefly described. These bones were from a young individual and were badly weathered and somewhat distorted.   It has seemed advisable, therefore, to give new descriptions based on the very complete and well preserved adult material found in 1933.

The astragalus is large and heavy, deeper at the distal extremity than at the proximal. The facet for the fibula is roughly triangular in outline, gently convex proximo-distally and slightly concave dorso-ventrally. The mesio-distal corner of the bone extends out in a well defined process, thus causing the facet for the internal malleolus to assume nearly the outline of a right angle. The dorsal facet for the tibia is large and gently concave in the transverse diameter; the lateral portion is slightly higher than the mesial. A narrow, shallow groove of considerable transverse extent separates the tibial from the navicular facet. This remnant of the neck is almost as reduced as that of *Coryphodon* and is much narrower and wider than that of *Pantolambda* (Osborn, 1898, figs. 6, 10, 12, 13). The facet for the navicular is very extensive and deep; it faces both distally and laterally and, on one specimen at least, is contiguous with both the cuboid

and sustentacular facets. The distal portion is convex
proximo-distally, the lateral portion concave. The facet for
the cuboid is irregularly egg-shaped in outline and contiguous
with the sustenacular facet on at least one specimen. The
sustentacular is the larger of the two plantar facets; both are
on about the same level and are gently concave. They do
not meet, being separated by a wide, deep groove which is
closed anteriorly. There is no astragalar foramen.

The calcaneum is very massive and nearly as broad as it is
long. The tuber calcis is short, very stout, oval in section
and wider in the transverse than in the dorso-ventral diam-
eter. The articular area for the astragalus is broadly
quadrangular, more so than in the various calcanei of *Cory-
phodon* figured by Cope (1877, 1884), and emarginate proxi-
mally and distally. The two facets are separated by a shallow
depression. The lateral side of the bone is concave beneath
the ectal facet and the ventral portion of this surface extends
out in a flat process. The tendons of the peroneus longus and
brevis occupied the broad groove thus formed; a prominent
but short ridge divides the distal extremity of this common
groove into two well marked smaller grooves for the reception
of each of these tendons. The plantar surface of the bone is
concave; there is a very prominent tuberosity on the mesial
portion. There is no facet for the fibula.

The cuboid is broad and stout and is closer in shape to
that of *Coryphodon* than to that of *Pantolambda*. The bone
bears a small, oval, raised facet for the ectocuneiform on the
middle of its mesial surface. There is no articulation between
cuboid and navicular, as in *Coryphodon*. The navicular is
narrow proximo-distally and very wide transversely, the
mesial side is strongly inclined proximally in an expanded
hook-like process. The articular area for the astragalus is
thus very concave and faces both proximally and laterally.
The navicular of *Coryphodon* figured by Osborn (1898, fig.
6) is somewhat similar, but does not have such a strong in-
ternal hook; the flat short navicular of *Pantolambda* is de-
cidedly different. Osborn states (1898, p. 185) that a tibiale

was probably present in *Pantolambda*.   There is no trace of
such a structure in the figured specimen of *Titanoides*.   The
ecto- and mesocuneiforms are irregularly shaped tetragonal
prisms with the greatest diameter in the antero-posterior
direction.   The ectocuneiform articulates with Mt. IV by

TEXT FIG. 6.   *Titanoides faberi*.   Right pes, P14945.   × ⅓.

two facets which are separated by a fairly deep pit.   The
entocuneiform is an irregularly shaped tetragonal prism with
the greatest diameter in the proximo-distal direction.

The metatarsals, except Mt. I, are slender, and small

compared with the size of the tarsus; in their slenderness they
resemble those of *Pantolambda* rather than those of *Corypho-
don*. Mt. I is short and relatively stout, the proximal and
distal articulations are very convex; this bone is decidedly
different from the slender, curved Mt. I of *P. bathmodon* and
more nearly resembles the corresponding metatarsal of *Cory-
phodon*. Mt. IV is the longest of the series and has a con-
siderably expanded proximal end. The lateral side of Mt. V
extends out in a large flat, triangular process on which the
tendon of the peroneus brevis inserted; the process is con-
siderably larger and more extensive than that of Mt. V of
Pantolambda. The phalanges, particularly the second, are
small and the unguals do not appear to be fissured. The foot
was more plantigrade than that of *Coryphodon* and rather less
so than that of *Pantolambda*.

The heritage characters of the pes definitely indicate
descent from a form in approximately the same stage of evo-
lution as *Pantolambda*. The articulations of the various
tarsal elements are similar in the two genera, the chief ex-
ception being the absence of a fibular facet on the calcaneum
of *Titanoides*. The slenderness of Mts. II–V [1] and the rather
high lateral portion of the dorsal tibial facet of the astragalus
are points of resemblance to *Pantolambda*. In the habitus
characters of the pes—*i.e.* more massive tarsus, shorter and
stouter tuber calcis, broader astragalus with larger dorsal
tibial facet, broader and thinner navicular, broader cuboid and
smaller phalanges—there is a decided resemblance to the foot
structure of *Coryphodon*. These habitus characters are the
result of the acquisition of size and weight by members of
the titanoidine phylum, a fact of great importance in ambly-
pod phylogeny and taxonomy. The articulations of the tarsal
bones of *Pantolambda* and *Coryphodon* are similar, with the
exception of the suppression of the cuboid—ectocuneiform
articulation in the latter genus. The graviportal *Titanoides*
supplies the desired link which shows that the pes of *Cory-*

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[1] I previously stated (1934, p. 93) that "If the pes of *Titanoides* had been found
isolated in the matrix it would, without much question, have been referred to the
Coryphodontidæ." This sentence must be emended to read tarsus for pes.

phodon could also have evolved from the pes of a panto-
lambdid in a similar stage of evolution to *Pantolambda* and
that the structural differences between the Torrejon genus
and *Coryphodon* may be regarded as due to graviportal adap-
tation in the coryphodont phylum.

Hind Limb Ratios.—The leg bones of P14908. collected in
1932 and reported on previously, were re-measured. The
new measurements are given here, together with those of
P14945 collected in 1933.

	Femur	Tibia	Tibio-femoral ratio	Mt 3	Metatarso-femoral ratio
P14908....	393	260	66	72 *	18
P14945....	489	309	63	88	18

* The metatarsal tentatively identified as the third in the previous report is shown
by the 1933 material to have been correctly determined.

Despite the dissimilarity in size and the poor preservation
of P14908, the ratios are essentially similar. They are inter-
mediate between those of *Pantolambda* and *Coryphodon*, but
somewhat closer to the latter, and are not so advanced as the
ratios of the fore limb (p. 152).

Affinities.—The material collected in 1933 confirms the
ideas that were advanced previously (1934, pp. 94–97) upon
the systematic position of the genus and its bearing on the
taxonomy and phylogeny of the Amblypoda. These state-
ments were as follows: (1) *Titanoides* is a member of the
Pantolambdidæ, (2) it was not descended from *Pantolambda*,
(3) it was not ancestral to *Coryphodon*, and (4) the resem-
blances in the structure of the feet, particularly the hind feet,
between *Titanoides* and *Coryphodon*, both graviportal forms,
are evidence that the feet of *Coryphodon* were evolved from a
pantolambdid type. The fact was pointed out that in dental
characters *Pantolambda* had been long regarded as an ideal
structural ancestor for *Coryphodon* and it was concluded on the
basis of (4) that "The Pantolambdidæ and Coryphodontidæ
may now be regarded as constituting a natural group in foot
structure as well as in the dentition."

The inclusion of *Titanoides* in the Pantolambdidæ is supported by nearly every feature of the osteology of the genus. The presence of chevrons is strong additional evidence that *Titanoides* was not descended from *Pantolambda*. The derivation of *Coryphodon* from *Titanoides* would necessitate such radical changes of structure and proportion as to seem directly impossible; both forms are large specialized members of divergent phyla. The resemblances and differences in the foot structure of these two genera are such as would be expected in late members of phyla which have diverged at different times from a common ancestral stock. The recently described family Pantolambdodontidæ (Granger and Gregory, 1934) from the upper Eocene of Mongolia must be added to the natural group Pantolambdidæ-Coryphodontidæ. *Pantolambdodon*, known only from lower jaws, is considerably closer to *Pantolambda* and *Titanoides* in dental structure than it is to *Coryphodon*.

No further evidence upon the position of the periptychids and uintatheres has been published since the report upon the 1932 collection. The Periptychidæ are still regarded as Amblypoda? inc. sed. and the Dinocerata tentatively considered a distinct order.

REFERENCES

COPE, E. D.   1877.   Report upon the Extinct Vertebrata obtained in New Mexico by Parties of the Expedition of 1874. U. S. Geog. Surv. west of 100th meridian, Vol. IV, Part II, Paleontology, pp. i–xii, 1–370.
    1884.   The Vertebrata of the Tertiary Formations of the West.   Book 1.   U. S. Geol. Surv. Terr., Vol. III, pp. i–xxxv, 1–1009.
GRANGER, W. AND GREGORY, W. K.   1934.   An apparently new Family of Amblypod Mammals from Mongolia.   *Amer. Mus. Novit.*, No. 720, pp. 1–8.
GREGORY, W. K.   1934.   A Half Century of Trituberculy.   The Cope-Osborn Theory of Dental Evolution.   *Proc. Amer. Phil. Soc.*, 73, pp. 169–317.
OSBORN, H. F.   1898.   Evolution of the Amblypoda.   Part I.   Taligrada and Pantodonta.   *Bull. Amer. Mus. Nat. Hist.*, 10, pp. 169–218.
    1929.   The titanotheres of Ancient Wyoming, Dakota and Nebraska.   U. S. Geol. Surv. Monograph 55, pp. i–xix, 1–894.
PATTERSON, B.   1934.   A Contribution to the Osteology of *Titanoides* and the Relationships of the Amblypoda.   *Proc. Amer. Phil. Soc.*, 73, pp. 71–101.

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DESCRIPTION OF SOME NOTOUNGULATES FROM THE CASAMAYOR (*NOTOSTYLOPS*) BEDS OF PATAGONIA*

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ABSTRACT

The skull and mandibles of *Notostylops murinus* of the Notioprogonia are described. The suggestion is advanced that the family became extinct as a result of inability to compete successfully with the more specialized and better adapted typotheres.

A description of *Pleurostylodon* of the Entelonychia, based on several incomplete specimens of *P. (?)biconus*, is given. The auditory region is described and some remarks are made upon the probable development of this area in the Notoungulata. Study of the skull and dentition indicates that the genus was in general rather conservative in structure. The unguals were of the hoofed type and indicate an animal of normal ungulate habits. It is considered that the Isotemnidæ and the Homalodotheriidæ were very closely related.

The typical Entelonychia are briefly discussed in the light of the material described, and of the excellent specimen of *Homalodotherium* in the collections of Field Museum. The group is compared with the Toxodonta and Typotheria and the conclusion reached that the Entelonychia retained more of the primitive notoungulate (= notioprogonian) heritage than either of the other two suborders.

Notopithecus of the Typotheria is described from a palate and two mandibles representing the species *N. secans* and *N. reduncus*. It is shown that the jugal is excluded from the vicinity of the orbit and restricted to the middle of the zygomatic arch. The lower dentition is taken as an example

* Results of the First Marshall Field Paleontological Expedition to Argentina and Bolivia, 1922–24.

to illustrate the evolution of the typotherean lower molar pattern in the gradual complication of the premolars. The genus is placed in the Interatheriidæ of which it is, at present, the earliest recorded member. It is pointed out that the small size and brachyodont dentition of *Notopithecus* suggest that the typotheres at this period were just entering upon their dental specialization, a supposition that is in accord with the theory that these animals replaced the less specialized Notostylopidæ in post-Casamayor time.

INTRODUCTION

The First Marshall Field Paleontological Expedition to Argentina sent out by the Field Museum under the leadership of E. S. Riggs collected fossil mammals chiefly from the Santa Cruz beds, the Colhué-Huapí (*Colpodon*) beds and from the Deseado (*Pyrotherium*) beds. Small collections were made also from the Casamayor (*Notostylops*) beds at two places; from Punta Casamayor on the Atlantic coast, and from the south end of Lake Colhué-Huapí in the interior of the Province of Chubut. At the latter place fossils were found in two localities, one at the base of the barranca facing the lake opposite the railway station, Kilometer 163; and the second in exposures three miles south of the railway station, Kilometer 145, some nine miles from the lake. The material collected consists of a few choice specimens, mostly described in the following pages, and a much larger number of jaws and fragmentary pieces.

Upon taking up the study of this collection we found that it was not particularly difficult to identify the more complete specimens, but that identification of the fragmentary material was practically impossible. The difficulty arose from the condition of the literature on this fauna. In various papers Doctor Florentino Ameghino described more than one hundred and twenty genera and some two hundred and sixty species from this formation. Many of his descriptions are very brief and accompanied by no figures. Anticipating this difficulty, the leader of the expedition asked permission to study the

great Ameghino collection while in Buenos Aires.   This was found to be impossible, as the specimens were at that time boxed up and stored in the basement of the Ameghino home. As a result it was decided to limit this paper to a description of such specimens as could be determined with some hope of accuracy, according to the existing nomenclature.

In the meantime, extensive collections of fossil mammals from the Casamayor formation were obtained by the Scarritt Patagonian Expedition from the American Museum of Natural History under the leadership of Doctor G. G. Simpson.   In the course of his work in Argentina, Doctor Simpson was able to study and photograph the Ameghino types which have recently come under the control of the Museo Argentino de Ciencias Naturales.   In view of these conditions, arrangements were made to coöperate with the American Museum in the study of the pre-Santa Cruzean faunas.   Following the preparation of this paper, the entire collections made by the Field Museum expedition from the Casamayor beds and from the Musters (*Astraponotus*) beds were placed at the disposal of the American Museum for the purpose of study and publication.   Also, in view of the large collections secured by the Field Museum from the Deseado and Colhué-Huapí beds it was likewise arranged that collections from these horizons recently secured by the American Museum should, after certain preliminary studies, be placed at the disposal of the Field Museum for study and publication.

An adequate knowledge of the mammalian faunas of the Casamayor and the Musters beds is one of the great desiderata in South American paleontology at this time.   By assembling all available collections of these faunas at one North American center of research, it is hoped to secure the most effective clarification of the problems involved.   With these earlier faunas better known, it is hoped more successfully to follow out the later lines of South American mammalian descent. The preparation of the pre-Santa Cruzean collections in this Museum has been skillfully performed by Messrs. J. B. Abbott and Sven A. Dorf of the Museum Staff.   The illus-

trations in this paper are from drawings by Mr. Sydney Prentice of the Carnegie Museum with some retouching by Mr. Carl F. Gronemann, Staff illustrator, Field Museum. To all these gentlemen we wish to express our sincere thanks. The manuscript of this paper was completed early in 1932. Since that time Doctor Simpson has contributed several preliminary publications which have necessitated some subsequent revision.

ORDER NOTOUNGULATA ROTH

SUBORDER NOTIOPROGONIA SIMPSON

Notostylopidæ

This family was erected by Ameghino in 1897 and referred to the Tillodontia on the basis of superficial resemblances in the dentition. Winge (1906, pp. 69, 96) placed it in the Typotheria but the majority of authors have referred it to the Entelonychia. We were at first inclined to agree with this view but Simpson subsequently showed, on evidence not available to us, that the endocranial cast of *Notostylops* is essentially similar to that of *Hegetotherium* and *Protypotherium* (1933 a and b), and that the family as a whole is more nearly related to the Arctostylopidæ and Henricosborniidæ than to the better known South American families (1934). His creation of the new suborder Notioprogonia to contain these three primitive and broadly ancestral families appears to be a valid and necessary step at the present time.

Notostylops Ameghino 1897

(Plates I, II; Text figs. 1, 2)

The best specimen of this genus available for description is a fine skull of a young individual, F.M. No. P13319, which has the full series of milk molars, with M^1 and M^2 fully developed and very little worn, and with M^3 not yet developed. The first permanent incisor is just appearing. A second and younger skull, P13308, shows also the milk

dentition with $M1^{\underline{1}}$ erupted.   In addition to these, there are
three maxillaries with teeth in varying stages of wear, and
four mandibles preserving between them the entire lower
dental series.   Figures of two skulls have been published by
Ameghino, *N. murinus* (1897, pp. 489–490, figs. 67–68) and
N. brachycephalus (1904 *b*, p. 412, fig. 540), and also some
figures of upper dentitions belonging to various species.
Gaudry (1904, figs. 15, 25, pp. 16, 20) has figured the upper
and lower dentition of *N. murinus* from specimens collected
by Tournouër, but hitherto no detailed description of this
important genus has been published.   Simpson (1932) has
recently given a good figure of *N. brachycephalus* in side view.
The skull (Plate I; Plate II, fig. 1) is relatively broad with
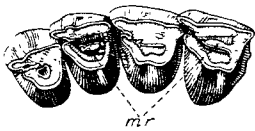
TEXT FIG. 1.   *Notostylops murinus*   TEXT FIG. 2.   *Notostylops murinus*
Ameghino.   P$\frac{1}{-}$M$^{\underline{2}}$, x$\frac{1}{1}$.   P14720.   Ameghino.   P$\frac{4}{-}$M^{1}, x$\frac{1}{1}$.   P13650.

On P$\frac{4}{}$ of P14720 and M$\frac{3}{}$ of P13650 independent or partially coalesced cuspules
may be seen in the median valleys.   m. r., median ridge.

long temporal fossæ, facial region short and constricted in
front of the orbits, cranial region relatively long, sagittal and
lambdoidal crests sharp and well defined, anterior nares wide
open and terminal, postorbital processes slight, auditory
bullæ moderately inflated, post-glenoid process compressed
antero-posteriorly.

Specimen No. P13319, referred to the species *N. murinus*
Ameghino and studied in the following description, has
probably attained about seven-eighths of the adult size.   The
presence of $M1^{\underline{1}}$ and $M1^{\underline{2}}$, with a broken cavity which ap-
parently contained the tooth-bud of $M1^{\underline{3}}$, together with the
erupting first incisor, all point to the conclusion that this
specimen is that of a young animal, not yet fully grown.
The second incomplete skull, specimen No. P13308, is referred
to from time to time in the following pages.

THE SKULL.   (Plate I; Plate II, fig. 1)

The skull may be compared with that of the well-known Santa Cruz form, *Adinotherium*, as follows: The skull of *Notostylops* is much smaller and is proportionately longer in the cranial region, is more constricted behind the orbits and is not so deep in the facial region. The sagittal crest is equally sharp, but longer, the arches are narrower, and the temporal fossæ more elongate. The occiput is similarly broad but more overhanging, as in *Homalodotherium*. The facial region is equally constricted in front of the orbits, the nasal bones are similarly elongate, the anterior nares are terminal and the premaxillaries much less massive. The cheek teeth are much more primitive.

The facial region of P13319, measured from the post-orbital processes is shorter than the cranial region in the proportion 82'100. The anterior rim of the orbit is above dm.^{4} the infra-orbital foramen above dm^3. The sagittal crest has a strongly convex outline and its length from the point of divergence of the temporal ridges is a little less than the distance from that point to the anterior margin of the nasals. The skull is low dorso-ventrally, as in *Homalodotherium*, but the facial region, due to the prominent premaxillaries, has a much more toxodont-like appearance than that of the last mentioned genus. The posterior half, only, of the zygomatic arch is preserved; this element is not nearly as broad dorso-ventrally as is that of the Santa Cruz entelonychian, although it resembles that form in that the arch joins the occipital crest at a lower level than is common in the Toxodonta and the Typotheria. The occiput overhangs the condyles, as in *Homalodotherium*; the structure of the auditory region is quite similar in the two genera (Patterson, 1932, pp. 6–12), the most distinctive feature in *Notostylops* being the antero-posteriorly compressed post-glenoid process.

When viewed from above, the skull of specimen P13319 appears in subrectangular outline as far as the antorbital margin, terminating anteriorly in narrowing nasals and premaxillaries. The transverse diameters across the orbits and

the occipital crest are approximately equal. The dorsal margin of the zygomatic arch is continuous with the occipital crest, and the conspicuous notches which indent the latter in *Homalodotherium* are not present. The overhanging occiput conceals the condyles from view as in this genus. The brain case is rather more prominent than in the Toxodonta and *Homalodotherium*, and narrows rapidly toward the very well-marked post-orbital constriction. The temporal fossæ are long and wide and the post-orbital processes of the frontals (restored in our figured specimens from Ameghino's figure of *N. murinus*) are very weak compared with those of the Santa Cruz Toxodonta and Entelonychia. The post-tympanic process of the squamosal and the porus acusticus externus are not visible in this view, as in *Homalodotherium*. The sagittal crest is very prominent on skull P13319, but in the younger specimen, P13308, this element is only slightly developed on the posterior third of the median line of the parietals and bifurcates anteriorly to form a long, low, sagittal area. The frontals, nasals and premaxillaries are of the toxodont type, as described and figured by Scott for *Nesodon* and *Adinotherium*, and are conspicuously different from the corresponding reduced and modified elements in *Homalodotherium*.

A similar outline is apparent in the ventral as in the dorsal view, the rapid tapering of the facial region being rather more noticeable. The bullæ are not so long antero-posteriorly as in *Homalodotherium*. The structure of the posterior narial opening in *Notostylops* is similar to that of the Santa Cruz entelonychian but the side walls do not diverge as much, they are not as thick, and there is no division of the choanæ (Patterson, 1934 *b*). Some of these differences, however, may be due to the distortion which this region has undergone.

The distortion suffered by the specimen renders a full description of all the bones of the skull impossible, but many of the sutures can still be detected. The limits of some of the bones, as described in the following pages, are tentatively

determined and must await the description of better preserved material for confirmation.

The *basioccipital* and *exoccipitals* are missing in all of the available specimens. The *supraoccipital* is rather narrow immediately above the foramen magnum but widens dorsally to form the entire occipital crest. The crest is confluent with the dorsal borders of the zygomatic arches without being emarginated by notches such as are present in *Homalodotherium*. The supraoccipital bone extends over the dorsal surface of the skull for a short distance thus excluding the parietals from any participation in the crest. There is a slight median ridge running from the foramen magnum to the crest, a contrast to the median groove which occupies the same position in the Santa Cruz entelonychian. The occiput as a whole is very similar to that of *Adinotherium*, being low dorso-ventrally and but little arched on the dorsal surface. It is, however, not so broad ventrally as in the latter genus and the post-tympanic processes of the squamosals do not participate so largely in its structure. The absence of deep concavities on each side of the supraoccipital, which are so conspicuous a feature in the occiput of *Homalodotherium*, is a distinct point of difference from that genus. To a slight extent, this lack may be due to distortion, but the concavities, even if present could not have been of any considerable depth.

The *sphenoidal elements* are unfortunately rather badly crushed on one side of the skull and lacking on the other, so that no definite description of them can be given. The only statement that can be made is that the alisphenoid was in contact with the bulla.

The *parietals* are long and narrow and extend anteriorly to the postorbital constriction. The sagittal crest on the older of the two skulls, P13319, extends the entire length of the median line of the parietals. At the point of divergence of these bones the crest divides into well-marked temporal ridges which extend over part of the frontals but in the specimen figured do not reach the postorbital processes. In the younger skull, P13308, an extensive sagittal area is present which

begins at the plane of the glenoid cavity and continues an-
teriorly to the forehead.   In a fully adult skull an even higher
sagittal crest than that of P13319 and more marked temporal
ridges might be expected.   The parietals diverge anteriorly
and the frontals project some distance between the divergent
ends.   Three or four vascular foramina are present along the
squamoso-parietal suture.

The *squamosals* are large and form a considerable portion
of the side walls of the cranium.   The glenoid cavity is narrow
antero-posteriorly and broad transversely with a very slight
lateral protuberance.   The postglenoid process of *Notostylops*
differs greatly from that of *Homalodotherium* in which this
element is long. massive proximally and tapering distally, and
channeled by the postglenoid foramen (Scott, 1912, p. 264).
In the Casamayor genus the process is very much compressed
antero-posteriorly and is not channeled by the postglenoid
foramen, which has only a small orifice at the suture with the
tympanic (Patterson, 1932, p. 12).

The dorsal border of the squamosal is raised to form a
ridge connecting the dorsal border of the zygomatic arch with
the occipital crest.   The post-tympanic process has a larger
lateral exposure than in the Santa Cruz Toxodonta and,
owing to the subrectangular form of the cranial portion of the
skull, a slightly larger exposure even than in *Homalodotherium*.
The occipital portion of this process is not so extensive as in
the Toxodonta.   Its dimensions approximate more nearly
those of *Homalodotherium*.   The epitympanic sinus is rela-
tively large and conspicuous in the dorsal, occipital and
lateral views, the lateral exposure, especially, being rather
extensive and the wall in this region thick.

The badly broken condition of the *jugals*—the anterior
portions of these bones are largely missing in the material at
our disposal—precludes a complete description but some
points of structure can be determined.   It would appear
from the older of the two skulls that the jugal forms the entire
arch, as in *Procavia*.   What appears to be a suture can be
detected on the left side of skull P13319 at the glenoid cavity.

Sutures at this point are also shown in Ameghino's figure of
N. murinus on both sides of the skull.   As additional evidence,
no trace of suture is visible on the half of the left arch that
remains.   Simpson, however, figures a normal squamoso-
jugal suture in the arch of *N. brachycephalus* (1932, fig. 2,
p. 3).   The short zygomatic process of the maxillary is
present in its entirety on the right side of the younger skull,
P13308, and exhibits the entire jugo-maxillary sutural area.
This area extends backward to a point immediately posterior
to the floor of the orbit and is comparatively shallow dorso-
ventrally.   This shallowness is in notable contrast to the
very considerable dorso-ventral depth of the jugal in *Homa-
lodotherium* which completely conceals the alveolus of the
third molar in side vew; in *Notostylops* $M^{\underline{3}}$ is fully visible.
The facial portion of the jugal is missing entirely on the older
skull but is partly preserved on the left side of the younger.
In this specimen it is present upon the face as a narrow strip
of bone forming the anterior rim of the orbit and extending
dorsally to the region of the lachrymal.   The same condition
is indicated by the jugomaxillary sutural area on the right
side of the skull.   This arrangement occurs throughout the
order with the exception of the Interatheriidæ and represents
essentially the same primitive condition as is exhibited by
the Condylarthra (Gregory, 1920 *b*, p. 176).   The *lachrymal*
is not preserved in either skull.

The maxillaries are similar to those of *Nesodon* and
Adinotherium and differ in many respects from those of
Homalodotherium, which is equivalent to stating that they are
of the normal toxodont type.   The facial portions of these
bones are relatively shorter and higher than in the Santa
Cruz entelonychian, in correlation with the unreduced pre-
maxillaries and the normal size of the nasals.   The bones do
not extend posteriorly over the orbits, as they do in the last
mentioned form, but have a fairly extensive contact with
the frontals just above and a little in front of the orbits.   The
infraorbital foramen is large and situated over the anterior
portion of $dm^{\underline{2}}$.   The zygomatic process is short and forms a

small part of the inner side of the arch. The palatine proc-
esses, while relatively smaller than in *Homalodotherium*,
make up the major portion of the hard palate. They are
deeply indented posteriorly by the palatines but not anteriorly
by the premaxillaries. The roots of the brachyodont teeth
do not form the concavity in the palate which is so noticeable
a feature in the hypsodont Toxodontidæ. From the widest
point, between the last pair of molars, the two sides of the
palate gently and regularly slope inward toward the median
line to form the apex of a triangle at the tip of the pre-
maxillaries.

The *palatines* are very indistinct in the older skull and
lacking in the younger, but their outlines are shown in Amegh-
ino's figures of *N. murinus* and *N. brachycephalus*. The
palatal portions extend anteriorly to the middle of $M^{\underline{1}}$ where
they are abruptly truncated, thus describing a rectangle on
the palate. To judge from Ameghino's figures, contact in the
median line ends at $M^{\underline{3}}$, which places the border of the
posterior nares farther forward than in *Homalodotherium*, in
which genus the median contact ends a little distance behind
the third molar. The ventral borders of the walls of the
posterior nares are not nearly so broad, relatively speaking,
as they are in the latter form, nor do they diverge so much,
although this latter condition may be due to distortion.
The limits of the *pterygoids* cannot be determined.

The *premaxillaries* are relatively large, with broad, as-
cending rami which have a considerable sutural contact with
the nasals, the two bones enclosing the large narial opening
laterally. This opening is cordate in outline and terminal,
as in *Nesodon* and *Adinotherium*. The opening is vertical,
and in side view has a concave profile due to the oblique,
upward sloping of the rami of the premaxillaries and the
overhanging nasals. The anterosuperior angles of the ros-
trum (in *N. murinus* at least) are upturned, forming blunt,
peg-like processes. The median symphysis is open in the
individual described but was doubtless closed in the adult,
as figured by Ameghino. The anterior palatine foramina

are relatively large but the spines separating them have been lost.

The *nasals* are long, rather wide, and convex transversely, bearing a strong resemblance to the corresponding bones of *Nesodon*. They are slightly divergent posteriorly while in the anterior extremities they are rounded and project considerably beyond the rami of the premaxillaries. They are more produced anteriorly but do not extend backward as far as do those of the Santa Cruz Toxodonta. They are relatively not so long as in these forms, this latter feature being due to the shorter facial region.

The *frontals*, as well as the premaxillaries and nasals, are decidedly toxodont-like in appearance. In fact, Scott's description of the frontals of *Nesodon* (1912, p. 138) might be copied here verbatim and would apply almost equally well to the genus under consideration, in which these bones are short and broad and the forehead nearly plane but sloping down a little over the orbits. Anteriorly the frontals are received into the shallow notch formed by the slight divergence of the nasals, and posteriorly into the deeper cleft between the parietals. Well-defined temporal ridges run from the sagittal crest towards the postorbital processes but do not reach them. The frontals have a considerable thickness near the postorbital constriction. The postorbital processes are much less prominent than in *Nesodon* [1] and the frontals do not roof over the orbits to such an extent as in the genus above mentioned. These are the only notable differences between the frontals in the two forms.

THE MANDIBLE (Plate II, fig. 4)

No mandible is associated with either of the skulls, the description here given being taken from two isolated specimens (P13447 and P13297) both of which are assigned to the genotypic species, *Notostylops murinus*. The two specimens supplement each other and permit a description of the

[1] Fide Ameghino's figure of *N. murinus*, from which those on the figured skull, P13319, have been restored.

entire jaw to be given, with the exception of the anterior
extremity of the symphysis and the coronoid process.

The mandible is large and robust.   The condyle is sessile,
almost as high above the level of the cheek teeth as in *Nesodon*,
Adinotherium and *Homalodotherium*, convex and broad trans-
versely, convex and narrow antero-posteriorly—the articular
surface being broader externally than internally in this dia-
meter—and with a pronounced slope downwards and inwards.
On the posterior side of the internal portion there is a small
articular surface for the postglenoid process, as is also the
case in *Homalodotherium* in which this surface is relatively
enormous, roughly elliptical in outline and equal in area to
that for the glenoid cavity.   This articular arrangement
permits very free lateral movement of the jaws.   The ascend-
ing ramus, in *Notostylops*, is broad antero-posteriorly, there
is no infracondylar notch and the angle is irregularly rounded,
the ventral border being a trifle below the ventral plane of
the horizontal ramus.   The angle is large with its free border
not thickened, except just below the condyle on P13447 where
there is considerable expansion.   The masseteric fossa is
rather well developed, with a median ridge for muscle attach-
ment, but the masseteric crest is not at all sharply defined.
The linea obliqua externa of the ascending ramus is fairly
conspicuous and extends ventrally to a point halfway down the
horizontal ramus under the second molar.   The dorsal portion
of this element is prominent and forms a fossa behind the
third molar, which is rather more prominent than that oc-
curring in *Homalodotherium* and *Adinotherium* but less so than
that in *Nesodon*.   The horizontal ramus is long, heavy and
robust, with a practically straight ventral border below the
cheek teeth.   Under the second premolar the ventral border
begins a rather abrupt upward turn to form a short, convex
chin as in *Homalodotherium*.   The symphysis is broad, heavy,
deeply concave on its dorsal surface, and extends posteriorly
to the third premolar.   The two mandibles are indistinguish-
ably fused in P13447, an old individual, and also in P13297,
a younger though fully adult specimen.   The dental foramen

is at the level of the cheek teeth. On P13447 there is a mental foramen beneath the diastema, and on P13297 beneath the third premolar.

The *hyoid arch* is unknown; the probable method of attachment of the arch to the skull in this genus and other notoungulates has been described elsewhere by Patterson (1932).

THE DENTITION

The usual dental formula is $I\frac{3}{2}$, $C\frac{0}{0}$, $P\frac{3}{3}$, $M\frac{3}{3}$ but variations from this occur. The first upper premolar is sometimes present, as is the canine, and the third upper incisor is reported lacking in one species. The second and third upper incisors, the first lower incisor, and, when present, the upper canine and first premolar are vestigial teeth and their presence or absence would appear to be of no functional or taxonomic importance.

Upper dentition (Plate I, fig. 2; Plate II, figs. 1–3; Text figs. 1, 2).—In the specimens at hand there is only one *incisor* preserved, an unerupted I^1 (Plate I, fig. 2; Plate II, fig. 1). In the absence of other teeth of this series, Ameghino's description of the incisors of *N. murinus* (1897, p. 488) may be translated to advantage: "The internal upper incisor on each side is well developed, not very large, fairly long, strongly arched, of limited growth and bears enamel only on the anterior face at the extremity of the crown, the posterior face being obliquely worn as in the rodents. The second and third upper incisors are rudimentary [vestigial]." An examination of the unworn incisor in No. P13319 reveals the fact that no enamel is present on the posterior face and also that the tooth is chisel-shaped before being abraded; the rodent-like appearance of this tooth is therefore not due to wear.

The cheek teeth are separated from the incisors by a considerable diastema and increase in size posteriorly to M^2. Both premolars and molars are rooted and the crowns are moderately long and higher on the labial than on the lingual side. In a freshly erupted tooth, the transverse diameter at

the summit of the crown is very much smaller than at the base. The grinding surface accordingly increases in width as the tooth is abraded.

The *premolars*. P$\underline{1}$ has been figured by Ameghino for *N. promurinus* (1904 *b*, fig. 534, p. 408) and by Gaudry (1904, fig. 25, p. 20) for *N. murinus*. Both of these figured specimens are, to judge from the state of wear of the teeth, young individuals and it appears possible that the supposed P$\underline{1}$ may be a remnant of the milk dentition. No example of the second premolar is preserved in the specimens at hand. The available figures show that it was much smaller than the succeeding tooth but apparently not dissimilar in structure. Premolars $\underline{3}$ and $\underline{4}$, preserved in Nos. P13299 (Plate II, fig. 2) and P13650 (Text fig. 2), are very similar in structure and differ mainly in size, P$\underline{4}$ being the larger. These teeth are trigonal and the transverse diameter is considerably longer than the antero-posterior. The ectoloph is sinuous, with a conspicuous parastyle and paracone, the two being separated by a vertical groove which is deeper on P$\underline{4}$ than on P$\underline{3}$. The lingual face is crescentic and there is no trace of a postero-internal cusp. The protoloph is oblique, low, and does not fuse with the ectoloph until the tooth is somewhat worn. A ridge occupying the position of an antecrochet is sometimes present. The metaloph is slightly shorter and straighter than the protoloph and joins the ectoloph near its posterior margin. The transverse lophs are very low in comparison with the ectoloph; consequently, when looking at an unworn molar or premolar from the front or rear the tooth exhibits a concave, V-shaped, grinding surface, with one arm of the V (the ectoloph) slightly higher than the other. The ectoloph is convex and curved inwardly on the cheek teeth of this genus, and also of most of the low-crowned Notoungulata, fore-shadowing the great degree of curvature attained by many of the later, hypsodont members of the order. The cingula are variable in different specimens. No trace of an internal one has been observed. The anterior and posterior, when present, are low and very little developed;

the external, sometimes lacking, is low and rounded. The protoloph and metaloph inclose an oval median valley which is divided by a ridge projecting from the metaloph (Text figs. 1 and 2) and extending anteriorly to the paracone. This ridge is formed by the union of cuspules (Patterson, 1934 a), which have arisen from the floor of the valley and united with each other and with the metaconule. On P^4 of specimen P14720 (Text fig. 1) some of these cuspules which have not yet coalesced with the metaloph may be seen. The antecrochet on the protoloph may also have developed from one of these cuspules.

The *molars* M^1 and M^2 are very similar in structure and may conveniently be described together. They differ from the premolars in their larger size, straighter ectolophs, and quadrangular outlines. The straightness of the ectoloph is due to the shallower groove between the parastyle and paracone; the quadrangular outline is due to the presence of a postero-internal cusp. There is no trace of an internal cingulum on the specimens at hand; the anterior and posterior cingula are low, weak and not always present. The external cingulum is variable in its degree of development but is generally rather more prominent than on the premolars. It is not sharply defined, but rounded, resembling in this respect the external cingulum of *Palaeostylops iturus* from the Paleocene of Mongolia (Matthew and Granger, 1925, fig. 2), although not showing the cusp-like elevation on the external cingulum of M^2 of that species. The protoloph is essentially the same as on the premolars; the metaloph runs backward and outward from the postero-internal cusp to join the ectoloph near its posterior extremity. The central valley is relatively larger than in the premolars but is similar in being divided by the median ridge. On most of the molars at hand no trace of the cuspules that make up this ridge remains. The unworn first molar of P13308 and the third molar of P13650, however, exhibit partially coalesced conules in the anterior half of the ridge, a condition resembling that shown by P^4 of the specimen figured above (Text fig. 2). The postero-internal cusp

of M¹ and M² is rather small and is situated on the posterior slope of the protocone, with which it becomes united by abrasion.   There is a very shallow depression between these two cusps on the lingual face of the tooth.   The posterior cingulum is small and far removed from the postero-internal cusp.   The position of the latter on the posterior slope of the protocone and its close connection with that cusp appear to indicate that it is a pseudohypocone.   A similar cusp is developed on the molars of the primate subfamily Notharctinæ of the North American Eocene, in correlation with the increase in size of the entoconids which shear across the posterior slopes of the protocones (Gregory, 1920 a, p. 149). The posterior cingulum of the molars of *Notostylops* is very low and shows no indication of having given rise to the postero-internal cusp.   The fact that the entoconids of the opposing lower molars shear between the protocones and the supposed pseudohypocones is evidence in favor of the supposition that the postero-internal cusp on the first two upper molars of *Notostylops* is a pseudohyocone.   The third molar is slightly smaller than the second and is trigonal in outline, due to the absence of the postero-internal cusp.   The structure, otherwise, is essentially the same as that of M¹ and M².

Each molar, when freshly erupted, is entirely covered with enamel of varying thickness, that on the lingual slope of the ectoloph, on the posterior slope of the protoloph, and on the anterior slope of the metaloph being considerably thinner than on the rest of the tooth.   The conditions in an unworn molar of *Homalodotherium* (Scott, 1912, p. 251) are somewhat similar, except that the enamel on the molars of the Santa Cruz genus is present on the above mentioned surfaces near the base of the crown only.

Lower dentition (Plate II fig. 4).—The *incisors*.   No complete tooth of the incisor series is present on any of the specimens at hand.   Ameghino, in his first description of the genus, stated that only one incisor, I₃, was present in the mandible and described it as "cylindrical, long, and without enamel save at the crown, which is short and flattened."

He later recognized (1901, p. 419) that a small second tooth $I_{\overline{1}}$, which he characterized as being "atrophied, small and cylindrical," was present beneath the larger I_2. The Field Museum specimens, in so far as they go, confirm this description. $I_{\overline{1}}$ is circular in cross section at the root, while I_2 is elliptical, with the greater diameter in the dorso-ventral direction.

The *premolars.* As far as is known at present there are only three lower premolars, but it should be noted that the lower jaw of *N. promurinus*, which supposedly has four upper teeth of this series, is as yet unknown. $P_{\overline{2}}$ is considerably smaller than its successor but is essentially similar in structure. The trigonid is higher and somewhat larger than the talonid, and its three component cusps are all united. The protoconid and the metaconid are almost connate. The paraconid has apparently been somewhat reduced. A shallow valley separates the paraconid from the metaconid-protoconid on the lingual side of the tooth. The talonid is fairly well developed, and rather sharply separated from the trigonid on the labial side by a vertical groove. The crista obliqua contacts with the trigonid midway between the proto- and metaconids. In the posterior valley between the metaconid and the hypolophid, there is a small, incipient cusp- the entoconid. This is the element that becomes so conspicuous a feature on the talonids of almost all notoungulates and which has been called by many writers the posterior pillar.[1] In the specimens at hand $P_{\overline{2}}$ has a large, single root, but in Ameghino's figure of *N. murinus* (1897, p. 491, fig. 70) this tooth is figured as being double rooted. The third and fourth premolars are practically molariform, resemble each other closely in structure though they differ in size, $P_{\overline{4}}$ being somewhat the larger of the two in all dimensions. They greatly exceed $P_{\overline{3}}$ in size and exhibit several advances over that tooth. The proto- and metaconids are

[1] The premolars of *Notostylops* are too specialized to permit an account of the development of the notoungulate lower molar pattern to be given here. For this the reader is referred to the description of the corresponding teeth of the contemporary typothere *Notopithecus*, in which the details of development are very clear (p. 206).

well separated, the talonids are larger and broader and equal the trigonids in size. The entoconid is now a large cusp on the postero-internal angle of the crown, independent on an unworn tooth but becoming connected with the posterior extremity of the lophid as abrasion proceeds. The para-conids are more reduced than on $P_{\bar{3}}$, foreshadowing their almost complete elimination on the molars.

The *molars*. The most important difference between the premolars and molars is the great reduction, in the latter, of the anterior horn of the trigonid (paraconid) and the conse-quent virtual reduction of the trigonid to the metalophid (proto + metaconid). The latter is straight, is situated more anteriorly upon the tooth, and presents less obliquely to the transverse axis of the tooth row than in the premolars. In correlation with this reduction of the trigonid, the talonid has increased considerably in size; the trigonid, however, is still the higher of the two on an unworn tooth. Apart from the reduction of the trigonid, the first two molars resemble the third and fourth premolars quite closely. $M_{\bar{3}}$ is dis-tinguished by the prolongation of the hypolophid posterior to the entoconid with the result that this cusp, instead of becoming joined, as in the anterior molars and premolars, to the posterior extremity of the lophid, joins it at a point nearer the center.

The *milk dentition* (Plate I, fig. 2; Plate II, fig. 1). The upper molars are the only teeth of the deciduous series that are present in the material at hand. They are four in number. In specimen P13319 the milk molars are rather well worn, the first permanent molar is in place and slightly worn, and the second shows no sign of wear and so has just erupted. The first incisor is barely erupted and had probably not yet displaced di^1. Dm^1 is a very small tooth, longer antero-posteriorly than transversely. The ectoloph is convex, the paracone is prominent, the parastyle is small, and the roots are united throughout most of their length, being free only at their lower extremities. It seems possible that this small and almost functionless tooth may have persisted in some

specimens until the permanent teeth came into place, and that the small $P^{\underline{1}}$ of N. *promurinus* and of the specimen of N. *murinus* figured by Gaudry, may in reality be the unshed $dm^{\underline{1}}$. The second milk molar is much larger than the first and is triangular in outline, with the transverse diameter exceeding the anteroposterior. In structure it closely resembles the premolars except for the parastyle, which is somewhat larger and more divergent from the paracone. There is no external or internal cingulum. The anterior and posterior cingula are low and very little developed. $Dm^{\underline{3}}$ is considerably larger than $dm^{\underline{2}}$ and shows a faint groove in the center of the lingual face which is lacking on the preceding tooth. Apart from this feature, there is no essential difference between the two teeth. The fourth milk molar closely resembles the permanent molars. It is the largest of the deciduous series and has a quadrangular outline, a postero-internal cusp and an external cingulum. It differs from the permanent molars and agrees with the preceding milk teeth in its more divergent parastyle.

The first molar was unquestionably, the first of the permanent dentition to come into place and was followed by $M^{\underline{2}}$ and then by $I^{\underline{1}}$. This order of eruption is, so far, very similar to that of *Nesodon*, as described by Scott (1912, p. 129), and it is probable that when the tooth succession of *Notostylops* is fully known it will not prove to be materially different from that of the Santa Cruz toxodont.

RELATIONSHIPS

We have nothing to add to Simpson's discussion of the general affinities of the genus (1934, pp. 10–16). *Notostylops* is a primitive but by no means an unspecialized form. Simpson (1932, p. 5) has listed several characters, such as the short rostrum, anteriorly placed orbits, diastemata, high sagittal and lambdoidal crests, in which the genus is highly adaptive. Among the primitive features may be mentioned the structure of the molars, the low porus acusticus externus

and the nearly parallel basifacial and basicranial axes. The genus seems to have been the first of the notoungulates to acquire a markedly rodent-like habitus but its inadaptive molar structure was probably a major factor in its extinction when faced with the competition of the better adapted, hypsodont typotheres (see p. 212).

SPECIES

Ameghino has very briefly described eleven species of *Notostylops*, of which number he has figured but four. His descriptions are brief and identification is consequently difficult and uncertain. No attempt has been made to work out synonymy or to give further diagnoses and comparisons of the species recognized, as we feel that these questions had better be left entirely to Doctor Simpson, who has had opportunity to examine the type specimens. He has kindly informed us that all our material is referable to *N. murinus*.

Notostylops murinus Ameghino (Plate II, fig. 4)

Notostylops murinus Ameghino, 1897, p. 489, figs. 67–70.
N. aspectans Patterson, 1932, p. 9, fig. 2.

MEASUREMENTS

	P13319 mm.
Length, upper milk molar series	22.0
Antero-posterior diameter of dm^1	4.0
Transverse diameter of dm^1	3.5
Antero-posterior diameter of dm^2	5.0
Transverse diameter of dm^2	6.7
Antero-posterior diameter of dm^3	7.0
Transverse diameter of dm^3	8.0
Antero-posterior diameter of dm^4	7.5
Transverse diameter of dm^4	9.0
Antero-posterior diameter of M^1 along ectoloph	10.0
Antero-posterior diameter of M^1	8.7
Transverse diameter of M^1	12.0
Antero-posterior diameter of M^2 along ectoloph	10.5
Antero-posterior diameter of M^2	9.5
Transverse diameter of M^2	12.0

	P13447 mm.
Length, $P_{\overline{2}}$–$M_{\overline{3}}$......................	49.0
Length, $P_{\overline{2}}$–$P_{\overline{4}}$.......	20.0
Antero-posterior diameter of $P_{\overline{2}}$....	4.7
Transverse diameter of $P_{\overline{2}}$.	3.0
Antero-posterior diameter of $P_{\overline{3}}$....	7.0
Transverse diameter of $P_{\overline{3}}$....	5.5
Antero-posterior diameter of $P_{\overline{4}}$....	8.5
Transverse diameter of $P_{\overline{4}}$......... . .	7.0
Length, $M_{\overline{1}}$–$M_{\overline{3}}$.........	29.0
Antero-posterior diameter of $M_{\overline{1}}$.	9.0
Transverse diameter of $M_{\overline{1}}$...	6.0
Antero-posterior diameter of $M_{\overline{2}}$	10.0
Transverse diameter of $M_{\overline{2}}$...	6.5
Antero-posterior diameter of $M_{\overline{3}}$..	12.0
Transverse diameter of $M_{\overline{3}}$.......	6.5

The skull measurements are rather uncertain, due to the distortion of the specimen, and too much reliance should not be placed upon them. Several important measurements, such as the basilar length, cannot be given owing to the absence of the exoccipitals.

	P13319 mm.
Skull, length from median incisive border to middle of occipital crest...	106
Skull, length from occipital crest to end of nasals....	100
Facial length [1]	46
Cranial length [2].	56
Skull, width across postorbital processes..	28
Skull, width across premaxillaries....	17
Skull, width at postorbital constriction..	14
Skull, zygomatic width....	58
Face, depth at $P^{\underline{4}}$...	28
Face, depth at M^{1}	32
Occiput, width across dorsal border of foramen magnum...	41
Sagittal crest, length...	45
Occipital crest, width	42
Zygomatic arch, length from glenoid cavity. . . .	40
Zygomatic arch, depth in posterior half..	11
Nasals, length in median line.	31
Palate, length in median line.	54

	P13447 mm.
Mandible, length (excl. incisors).....	106.0
Mandible, depth at $P_{\overline{3}}$.......	18.0
Mandible, depth at $M_{\overline{1}}$	20.0
Mandible, depth at $M_{\overline{3}}$	22.2

[1] From median incisive border to middle of line connecting posterior borders of orbits (Osborn).

[2] From middle of line connecting posterior borders of orbits to middle of occipital crest (Osborn).

Localities.—P13447 and P13650 were collected by Mr. J. B. Abbot at Punta Casamayor. The others were found by Mr. G. F. Sternberg at Lake Colhué-Huapí. Ameghino does not state where his specimens were obtained.

SUBORDER ENTELONYCHIA AMEGHINO
ISOTEMNIDÆ

This family was originally placed by Ameghino in the now discarded order Ancylopoda, together with the Homalodotheriidæ and the Leontiniidæ. Its very close relationship with the former family has been generally recognized and it has been referred to the Entelonychia by most subsequent writers. As originally defined by its author, one of the most characteristic features of the family was the supposedly equal size and similar appearance of the incisors, canines, and first premolars (Ameghino, 1897, p. 479), a character which was restated by Loomis in his work on the Deseado fauna (1914, p. 129). In the meantime, however, Ameghino had revised his original diagnosis and stated (1901, p. 410) that in some forms the canine "was more or less enlarged." The specimens here described and figured are all referred to *Pleurostylodon*. They are the most complete so far described and permit the observation of several new characters. So many forms have been described, but not figured, by Ameghino, that the writers are unable to judge whether features recorded for *Pleurostylodon* are common to other genera of the family. In consequence no revision or additions to previously published diagnoses of the Isotemnidæ is here attempted.

Pleurostylodon Ameghino, 1897 (Plates III, IV; Plate V, fig. 1)

This genus is represented in the Field Museum collections by four specimens as follows: A skull, P13528, somewhat crushed and compressed; the anterior half of a young adult skull, P13296, with canine and unworn cheek teeth; the anterior portion of a somewhat older adult skull, P13309, with canine and premolar teeth; and a fragmentary right maxillary, P13620, with dm^{2}, dm^{4} and $M_{\overline{1}}$–$M_{\overline{3}}$, associated

with fragments of limb bones and two incomplete phalanges. There are no lower jaws in the collection which may be certainly identified with this genus. Upon this material the following description is based.

Pleurostylodon is closely comparable to *Homalodotherium*, the best known and one of the latest of the entelonychian genera. In the general proportions of the skull, the structure of the arches, the structure of the auditory region, and the dentition, the two forms have much in common. While *Pleurostylodon*, as will be pointed out below, is a more primitive animal, it displays in its cranial and dental anatomy structures which were doubtless characteristic of the ancestral stock from which *Homalodotherium* evolved. The specimens at hand, which are identified as *P. (?)biconus* Ameghino, with the exception of P13620, indicate an animal slightly smaller than *Rhynchippus equinus* of the Deseado.

The Skull (Plates III, IV; Plate V, fig. 1)

The specimens in the collections are neither sufficiently complete nor sufficiently supplementary to admit of a full description of the skull. The distorted skull, P13528, has been very skillfully and, so far as can be judged from the specimen, accurately restored by Mr. Prentice in his drawing (Plate III). This specimen admits of a general description in ventral view and a fairly detailed account of the auditory region. From the two anterior halves, P13296 and P13309, (Plate IV, figs. 1, 2) a general description of the bones of the face can be given. The occiput and the dorsal aspect of the cranial region remain unknown.

The skull is rather broad across the arches, with the widest point at the glenoid cavities. The facial portions of the maxillaries slope rapidly outward from the muzzle to the anterior rims of the orbits. The arches present a sharp angle opposite the glenoid cavity. The muzzle and the occiput are gently rounded. The palate is comparatively wide, the tooth-rows are slightly curved and diverge toward their posterior extremities.

In comparison with *Notostylops*, the skull is much larger and the muzzle less constricted. The facial regions of the two genera show considerable differences; that of *Notostylops* is triangular, with prominent first incisors and conspicuous diastemata, while *Pleurostylodon* has a broad muzzle, rather small first incisors, and no diastemata. In comparison with *Adinotherium* of the Santa Cruz beds the genus under consideration has a narrower occiput, a considerably shorter and less tapering facial region, and a less reduced dentition. The second incisor of *Adinotherium* is greatly enlarged, while the third incisor and canine are vestigial and isolated by small diastemata. There are considerable differences in the auditory region also which will be discussed further on (p. 190). *Pleurostylodon* differs from *Homalodotherium* in having a less regularly oval skull, shorter facial region, unreduced nasals and relatively longer canines. The two genera, however, closely resemble each other both superficially and fundamentally.

The anterior rim of the orbit of *Pleurostylodon* is above the middle of the first molar. The infraorbital foramen is situated above the posterior border of $P^{\underline{3}}$. The jugal resembles that of *Homalodotherium* and differs from those of the Toxodontidæ in the absence of a notch for the reception of the zygomatic process of the squamosal. The arch, as a whole, is narrower and less robust than that of the Santa Cruz entelonychian. The jugal elements is much shallower dorso-ventrally, leaving the alveolus of the last molar visible in side view. The glenoid articulation is elongate transversely, and narrow, with a deep fossa behind. The postglenoid process is slight. The structure of this area is very similar to that of the Santa Cruz toxodont, *Adinotherium*.

The facial region is of the normal notoungulate type, *i.e.* having the anterior nares terminal in position, the nasals long and rather robust and with a sutural contact with the premaxillaries and maxillaries, and a fronto-maxillary articulation above the orbit. It is similar in a general way to that of *Notostylops*, *Nesodon* and *Adinotherium* and it is

correspondingly unlike that of *Homalodotherium*. The speci-
men, P13528, shown in side view on Plate V, has been ab-
raded so that the superior outline cannot be reconstructed.
The facial region of P13296, is illustrated in Plate IV, fig. 1.
This specimen, in connection with a third, P13309, shows
that the nasals overhang the aveolus of the second incisor and
are proportionately longer than those of *Notostylops* or of
Adinotherium. The bones are narrow above the canine
alveolus, and expand slightly near their posterior ends. The
posterior margins are indented to receive the small, blunt
anterior processes of the frontal bones. The latter are
similar to the corresponding bones of *Adinotherium* though
with less prominent postorbital processes and less marked
by temporal ridges.

   The ascending process of the premaxillary is broad and
triangular, and has a long articulation with the nasal bone.
The alveolar border and the palatal surface are not well
preserved in the specimen at hand. Likewise, the form of
the anterior nares cannot be determined. It is apparent
that they were terminal in position and thus very different
from the widely open nares of *Homalodotherium*. The maxil-
lary, as might be expected from the structure of the adjacent
facial bones, is of the more conservative pattern known from
the Santa Cruz genera, *Nesodon* and *Adinotherium*. The
facial portion is shorter than that of *Homalodotherium*. It
terminates in a rounded angle above the anterior margin of
the orbit and joins the frontal in a short, transverse suture.
The zygomatic process of the maxillary is short and is over-
lapped by the jugal so as to be almost concealed in the lateral
view. The jugal, as is usual in the Notoungulata, forms a
part of the anterior rim of the orbit and excludes the maxil-
lary. The lachrymal bone is not preserved in the specimens
at hand. Apparently it was mostly within the orbit as in
Nesodon.

   The auditory region of the older adult skull, P13528
(Plate III), is fortunately quite well preserved and permits a
fairly detailed description to be given. It is of the usual

toxodont type but rather more generalized than that of *Homalodotherium*.

The *tympanic*.[1] The auditory bulla is very similar to that of *Homalodotherium*, being oval in outline, well inflated, and having the greatest diameter in the antero-posterior direction. The auditory meatus is cylindrical in form and is directed slightly backward and upward. The crest on the under surface of the meatus (crista meati) is neither as massive nor as rugose as that of the Santa Cruz entelonychian but is thinner antero-posteriorly and less extended ventrally. It is partially hidden by the pars serialis of the squamosal in the occipital view. There are no processes from the crest, either abutting against the distal end of the post-tympanic process as in *Homalodotherium* and *Notostylops*, or joining the paroccipital process as in *Homalodotherium*. The crest joins the bulla in the same manner as in *Nesodon* and *Adinotherium;* that is, it runs obliquely forward and inward from the porus and joins the bulla at the middle of its lateral surface. The porus is comparatively large, placed low on the side of the skull, circular, and bounded anteriorly and ventrally by the tympanic, dorsally and posteriorly by the squamosal. The post-glenoid foramen is large and conspicuous, and channels both the post glenoid process and the crest.

The *epitympanic sinus* is situated above and behind the porus and is conspicuous in both occipital and lateral views.

The *stylomastoid foramen* has the position usual in the order: that is, intermediate between the porus and the hyoidean vagina. It is bounded anteriorly by the crista meati and posteriorly by the post-tympanic process. The orifice is not so conspicuous as in *Homalodotherium*, being partially hidden in the cleft between the crest and the post-tympanic process.

The *vagina processus hyoidei* is situated at the postero-external surface of the bulla, as is the rule in the order. It

[1] It is possible that an entotympanic is present but such an element was not detected at the time this account was written.

is bounded antero-internally by the bulla, antero-externally by the crista meati, and posteriorly by the paroccipital process. No trace of a mastoid process or of an adventitious bone (Patterson, 1932, p. 19) can be detected. These elements may be present, as the skull is that of an old individual in which the sutures are indistinct. The paroccipital process is comparatively short, stout and curved posteriorly.

The auditory region of *Pleurostylodon* appears to be more generalized than that of any other notoungulate so far described.[1] It has all the usual features of the notoungulate auditory region but none of them are at all accentuated. When compared with *Adinotherium* of the Toxodontidæ, the tympanic region of *Pleurostylodon* is immediately seen to be of a more simple type. In *Adinotherium* the basicranial region is shortened antero-posteriorly, the occiput is wide, the post-glenoid and post-tympanic processes of the squamosal are very close together and the crista meati is, in consequence, thin and plate-like. The mastoid is excluded from the side of the skull, is restricted to the occiput and is exposed there in young specimens only. The porus is rather high on the side of the skull and the bullæ have their greatest diameter in the dorso-ventral direction. In *Pleurostylodon* and also in *Notostylops* and *Homalodotherium*, the basicranial region is relatively longer antero-posteriorly, the post-glenoid and post-tympanic processes are farther apart, the tympanic crest is thicker, the porus is lower and the bullæ are longer antero-posteriorly. The mastoid is extensively exposed in *Homalodotherium* and probably, although not yet definitely known, in the other two genera also. The more specialized conditions in *Adinotherium*, in other members of the Toxodontidæ, in the Leontiniidæ and in the Typotheriidæ, seem to have arisen in correlation with two factors: The first appears to have been the great expansion of the epitympanic sinus, an expansion greater than that of any known entolonychian, which contributed to the very considerable broadening of the

[1] The members of the Interatheriidæ and Hegetotheriidæ of the Typotheria should, perhaps, be excepted. While the members of these two families have a broader occiput and a larger epitympanic sinus, they have no well defined crista meati.

occiput and the exclusion of the mastoid from the side of the skull.[1]   The second factor is that *Adinotherium* has acquired a certain degree of cyptocephaly (Osborn, 1931, p. 256), *i.e.* a bending down of the basifacial axis upon the basicranial, with which the antero-posterior shortening of the basicranial region and the attendant features listed above seems to have been associated.[2]   It seems probable that, in the earliest members of the Notoungulata, the basicranial and basifacial axes were on the same plane and the occiput was not particularly broad.   The auditory region probably had the following characters: bulla moderately inflated with the greatest diameter in the antero-posterior direction, auditory meatus cylindrical with a slight crest on the under surface, porus situated low down on the side of the skull, epitympanic sinus small.   From these hypothetical prototypes, which if known would probably be placed in the Notioprogonia (Simpson, 1934), the known Entelonychia have diverged the least of any of the three later suborders.   The most noticeable subsequent developments in this group were complications of the crista meati, such as the processes in *Homalodotherium*.

THE DENTITION (Plates III, IV; Plate V, fig. 1)

In the skull the full therian dental formula, $I^{\underline{3}}$, $C^{\underline{1}}$, $P^{\underline{4}}$, $M^{\underline{3}}$, is present.   The formula of the mandible is not recorded by Ameghino, but there is no reason to doubt that the full complement of teeth was present.   The upper tooth rows diverge but little posteriorly.

Upper dentition.—The *incisors.*   The first and second teeth of this series are very similar in structure and also in

[1] In a previous paper it was stated (Patterson, 1932, p. 23) that, with a few exceptions, a very little exposed or hidden mastoid was characteristic of the Notoungulata.   In the light of the above this statement is shown to be probably incorrect. It is a specialization attained by many of the Toxodonta and Typotheria but not, apparently, by the Entelonychia and Notioprogonia.

[2] Among perissodactyls, Professor Osborn has attributed such features as the exclusion of the mastoid from the side of the skull and the antero-posterior compression of the basicranial elements, to brachycephaly.   It would appear, however, that brachycephaly cannot be responsible for similar conditions among the Notoungulata for the majority of skulls measured by us (using Osborn's measurements for the Perissodactyla, 1931, p. 256), including those genera with expanded occiputs and compressed basicranial regions, are either mesaticephalic or subdolichocephalic.

size, I^2 being slightly the larger. They are gently convex on the labial face, which exhibits no trace of a cingulum, and were probably conical in shape when unworn. On the lingual face there is a strong, vertical median ridge which is flanked by fairly deep concavities. An internal basal cingulum is present, which in some teeth is continuous over the ridge, and in others is not. The third incisor is much enlarged and is apparently in the process of assuming the lanceolate shape of the canine. Instead of being squarely abraded across the top, as are the first and second incisors, it is worn on the inner side of the posterior half, as are the canines. The structure, both of the labial and lingual faces, is, however, the same as that described for the preceding teeth.

The *canine* is subject to individual variation. It is approximately one-third larger than I^3, lanceolate, strongly convex on the external face, flat on the internal; it bears a conspicuous internal vertical groove near the antero-internal border and lies obliquely to the antero-posterior axis of the cheek-tooth row. The presence or absence of an external cingulum is variable as two specimens show no trace of it while a third bears a rather weak one. The same specimen has an internal cingulum on the anterior third of the lingual face beneath the vertical groove. The canines of P13528, are obliquely abraded on the posterior half of the internal face, while those of P13309, in addition to exhibiting wear in the same position as in the preceding, are also worn on the anterior portion of the labial face.

The *premolars*. The first premolar is small, single-rooted and roughly elliptical in outline, with the long axis in the antero-posterior direction. This tooth is so much worn in all the specimens at hand that it can only be observed that an external cingulum is present on the posterior two-thirds of the ectoloph and that the protoloph is not formed. The second premolar is considerably larger than P^1, quadrangular in outline and three-rooted, two external roots and one internal; the ectoloph is convex and very undulating with a prominent parastyle which slightly overlaps P^1. The parastyle is

followed by a deep vertical groove which sharply separates
it from the conspicuous paracone, which is itself set off
posteriorly by a much shallower second groove, and there is a
very slight elevation at the metacone.   A rather weak ex-
ternal basal cingulum extends posteriorly from the parastyle.
The protocone is a large cusp situated in the middle of the
lingual face of the tooth; the long, obliquely-lying protoloph
joins the parastyle, and the shorter and straighter metaloph
joins the ectoloph just posterior to the metacone.   There is
no postero-internal cusp on this tooth or on either of the two
succeeding premolars.   The anterior cingulum on P^2 is
extremely well developed on the antero-internal corner of the
tooth, the nearest approach that the writers have observed
in a notoungulate to the extreme development of the anterior
cingulum in the later Macraucheniidæ.   It extends over to
the internal face terminating at the base of the protocone, in
some cases extending partly around it.   The posterior cin-
gulum is placed somewhat nearer the apex of the tooth than
is the anterior and accordingly soon loses its identity in the
grinding surface.   It is poorly developed on the posterior
face of the tooth but is reflected over upon the internal face
and attains some prominence on the postero-internal corner,
enclosing, together with the protocone and the metaloph, a
small fossette which persists for a short time before being
worn away.   The posterior cingulum ends on the posterior
side of the protocone, where the difference between the levels
of the two cingula is very noticeable.   The central valley is
very deep and lies obliquely across the grinding surface in a
little abraded tooth, becoming more and more antero-
posterior in position as abrasion proceeds.   The valley is
invaded by three or four cristæ from the ectoloph, the pos-
terior of which unites with a crochet from the metaloph to
isolate a small fossette.   On the posterior slope of the proto-
loph there is a small vertical ridge, corresponding in position
to an antecrochet.[1]   On the premolars of P13296, a young

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[1] The terms cristæ, crochet and antecrochet are employed as topographical names
and do not necessarily imply developments homologous to those observed in other
orders.

animal, several of the cristæ are bulbous at their free extremities and on viewing them through a binocular microscope, it becomes evident that the bulbous ends are connected to the ectoloph by a thin ridge of enamel.   It would seem as though cuspules had arisen in the median valley, as in *Notostylops*, and later had become joined to the ectoloph.

The fourth premolar is larger than the third, both teeth have relatively greater transverse diameters than P^2.   Differences in structure from this tooth are trifling and appear to be limited to the cingula.   On P^3 the anterior and posterior cingula just meet on the labial face of the tooth; on P^4 they are continuous but the posterior is considerably lower than the anterior.   The external cingulum is variable in the teeth of this series; on P^4 it has its inception at the paracone, on P^3 either at the parastyle or paracone, and on P^2 at the parastyle.

The *molars:* M^1 and M^2 are quadrangular in outline and closely comparable in size, structure and proportions; the antero-posterior diameters are considerably greater, relatively, than in the premolars but do not equal the transverse.   The ectolophs are sinuous with prominent parastyles and paracones and gently convex metacones.   The external cingula, when present, are confined to the depressions between the paracones and metacones.   The anterior cingula are confined to the anterior faces of M^1 and M^2 of P13528 but on P13296 they are large and encircle the protoloph.   The posterior cingula are situated nearer the apices of the crowns and become fused with the metalophs when the teeth are moderately abraded.   The protolophs are long, oblique and join the parastyles; the metalophs are short, transverse and unite with the ectolophs immediately posterior to the metacones. The labial faces are incompletely divided.   On both M^1 and M^2 a variable number of cristæ extend from the ectoloph into the obliquely-lying central valley.   The posterior crista on each tooth is fused with the crochet, isolating a small fossette. On M^2 there is a small antecrochet on the protoloph.

The third molar differs from the preceding teeth of the series in its triangular outline, more sinuous ectoloph and

undivided labial face.   The anterior cingulum encircles the base of the protoloph; the posterior is placed low on the side of the tooth and participates in the crown pattern.   On specimen P13296 it is so prominent as to form an incipient hypocone.   The structure of the central valley is essentially similar to that of M^2; small cuspules occur on the floor of an isolated M^3, of P14870.

Very little is known of the *lower dentition*.   There are no mandibles associated with the skull material in the collections of this Museum.   Ameghino (1897, p. 484) states that the lower molars of *P. biconus* have a high crown, a slight internal cingulum, and a transversely elongated postero-internal tubercle (entoconid).   The same author described (1904 *a*, p. 240) the lower canine of *P. bifidus* as resembling $P_{\overline{1}}$ in crown pattern and having the root divided by a longitudinal groove.   Matthew (1915, pp. 430–432, figs. 1–3) and Schlosser (1923, p. 615, fig. 760) give figures of $P_{\overline{1}}$ and the lower molars which show the elongated entoconid.   A complete jaw has not yet been figured or described but it is probable that the full dentition was present, as in the skull.

Milk dentition.—In P13620, *Pleurostylodon* sp., dm^{1-3} and M^{1-2} are in place and in use, M^3 is fully formed but is not yet in use.   The milk molars are so worn that little of their structure can be made out, but the parastyles are rather more divergent than on either the premolars or the permanent molars, and there is a pronounced concavity on the ectoloph between the paracone and the metacone.   The last three premolars are fully formed and are in place beneath the milk molars, which they would presumably have replaced at about the time M^3 came into use.

The dentition with its full complement of teeth appears to be a conservative one, exhibiting but a single specialized character—the tendency of the third upper incisor to become caniniform.   This, of course, does not imply that the premolars and molars are not progressive in the complexity of their crown patterns, or that they are less specialized than the cheek teeth of *Notostylops*.   The dentition of *Pleuro-*

stylodon and also that of *Homalodotherium* is conservative
in the sense that it is complete, rooted, and in series, and that
there are no functionless teeth on the verge of disappearance,
no disatemata, and no great development of any of the
anterior teeth such as occurs in *Notostylops*, *Leontinia*,
Nesodon, *Toxodon*, and others. The Notohippidæ among
the Toxodonta resemble *Pleurostylodon* in the above respects
but have acquired, in the course of their evolution, hypso-
donty and cement, progressive characters which the genus
under consideration is very far from attaining. In compari-
son with *Homalodotherium*, the teeth of *Pleurostylodon* are
seen to be more primitive, save, perhaps, for the development
of the third incisor, in that the upper canines are unreduced,
the upper premolars show no indication of a labial division,
and the third upper molars are considerably smaller and less
developed than the first and second. However, these differ-
ences are mainly such as would be expected between two
closely related genera from rather widely separated geologic
horizons. The development of the anterior cingulum on the
premolars and the incipient enlargement of I^3 possibly
represent divergences between the two genera. An adequate
knowledge of the Homalodotheriidæ of the Casamayor beds
is essential before satisfactory comparisons between the two
families can be made, but it appears certain from the available
material that the Homalodotheriidæ and the Isotemnidæ
are as close to each other in dental characters as they are in
cranial structure.

UNGUALS

The terminal phalanges of this genus, and probably also of
the other genera of the family, are of the hoofed, and not of
the specialized claw-like type which is so characteristic of
those homalodotheres in which these bones are known.
Authority for this statement is provided by two incomplete
unguals of *Pleurostylodon* sp., P13620, collected by E. S.
Riggs at Punta Casamayor in association with some frag-
mentary limb bones and the upper milk molar-molar dentition
described above.

One of these unguals, the larger and more flattened of the two, is from an internal digit, possibly from digit III. The other, which is smaller and more compressed laterally, is presumably from one of the external digits. This latter bears some resemblance to the unguals of the Santa Cruz typotheres. Whether the bones in question are from the fore foot or the hind foot is not certain. Probably they are from the hind foot, as the recognizable limb bone fragments are from the hind legs. The unguals are relatively low dorso-ventrally, in comparison with those of *Homalodotherium*, and taper rather rapidly towards their distal extremities. In the portions preserved (the distal ends are unfortunately broken off) there is no trace of a cleft or of any conspicuous rugosities, both of which features are very marked in the Santa Cruz entelonychian. If these bones were cleft at all it was obviously to nothing like the extent seen in *Homalodotherium*. The articular facets are low dorso-ventrally in comparison with those of the Santa Cruz form. Immediately above their broken ends the unguals begin to expand laterally, as in the typotheres and toxodonts. The claw-like unguals of the Santa Cruz entelonychian combined with the peculiar structure of its humerus and feet have been interpreted as indicating fossorial habits. The unguals of *Pleurostylodon* suggest more normal ungulate, and hence less aberrately specialized, habits than those of *Homalodotherium*.

RELATIONSHIPS

From the summary of characters of the dental series (p. 195) and of the auditory region (p. 190) it is apparent that *Pleurostylodon* is a rather generalized type that displays no great structural aberrations. The dentition indicates that it is an entelonychian closely related to *Homalodotherium*, and the structure of the skull in no way contradicts the inferences derived from the teeth, as definite and significant structural resemblances to *Homalodotherium* are clearly recognizable. In only one important cranial feature does *Pleurostylodon* differ from its Santa Cruz relative; that is, in the structure

of the bones of the face. These are of the normal toxodont type, as represented by *Adinotherium*. In this character *Homalodotherium* appears to be a highly specialized form and as such offers no barrier to close relationship between the Homalodotheriidæ and the Isotemnidæ. The precise relationship of the two above-mentioned families cannot be definitely determined owing to the lack of adequate knowledge of members of the Homalodotheriidæ frcm the Notostylops beds, but it is certain that the two are very closely related.

<div align="center">SPECIES</div>

The condition of the literature on the species of this genus is similar to that found on the species of *Notostylops*. Fourteen species of *Pleurostylodon* have been briefly described by Ameghino, several of them being based on isolated third upper molars. Of these fourteen species ten have been figured, but the figures, being mostly of single teeth, are inadequate for the determination of species.

The specimens in the Field Museum are, with the exception of P13620, from the region south of Lake Colhué-Huapí, and agree very closely in size. This material is tentatively assigned to *P. biconus* Ameghino, since the individual variations shown do not appear sufficient to establish the presence of more than one species of the genus in the collection from this locality. From an examination of Ameghino's figures it appears likely that he did not sufficiently consider individual variations in establishing his numerous species and that some of them will be found to be synonyms when the types are critically restudied.

Pleurostylodon biconus Ameghino, Plates III, IV; Plate V, fig. 1.

Trimerostephanos biconus Ameghino, 1897, p. 484.

Pleurostylodon biconus Ameghino, 1902, p. 29.

This species was originally founded on the lower dentition, and was transferred to *Pleurostylodon* upon the discovery of the upper teeth. Ameghino's second description may be

appended in translation: "Upper and lower canines differ-
entiated but not very large; upper canine with a short, conical
crown, a little arched and obliquely worn on the posterior face;
lower canine with a lanceolate crown, laterally compressed,
pointed, and with trenchant edges.   The upper molars re-
semble those of *P. modicus* [Ameghino, 1897, pp. 485–486]
but do not have an external basal cingulum.   Last upper
molar with an enamel cingulum at the base of the internal
side.   Surface of the enamel smooth or almost smooth."
The measurements given are as follows: $M_{\overline{1}}$, antero-posterior
diameter 15 mm., transverse diameter 20 mm.; $P_{\overline{3}}$ $M_{\overline{3}}$,
length 65 mm.; height of the ramus under $M_{\overline{1}}$, 22 mm.   The
canines and the cingula are apparently variable, as has been
explained above in the description of the dentition.

MEASUREMENTS OF DENTITION

	P13528 mm.	P13296 mm.	P13309 mm.
I^1 antero-posterior diameter.....	4.5		
I^1 transverse diameter...... .	7.5		
I^2 antero-posterior diameter..... ..	4.5		5.0
I^2 transverse diameter......	9.0		9.0
I^2 height of unworn crown . .	8.0		
I^2 antero-posterior diameter..	6.0		6.5
I^2 transverse diameter.....	10.0		10.5
I^3 height of unworn crown.....	11.0		
Canine antero-posterior diameter....	9.5	11.0	12.0
Canine transverse diameter.....	9.0	6.5	8.5
Canine height of crown ..	15.0	16.0	
Cheek tooth series, length ...	77.0	78.0	
Premolar series, length ...	39.0	40.0	41.0
P^1 antero-posterior diameter..	9.0	9.0	9.0
P^1 transverse diameter... .	8.0	8.0	7.5
P^2 antero-posterior diameter. .	10.0	10.0	10.5
P^2 transverse diameter..... .	14.0	13.0	13.0
P^3 antero-posterior diameter. .	11.5	11.0	10.5
P^3 transverse diameter....	16.5	16.5	17.0
P^4 antero-posterior diameter..	10.0	11.5	12.0
P^4 transverse diameter.....	19.5	19.0	18.0
Molar series, length. .	40.0	41.0	
M^1 antero-posterior diameter....... .	14.0	14.0	
M^1 transverse diameter	21.0	19.5	
M^2 antero-posterior diameter.... . ..	13.0	13.0	
M^2 transverse diameter...	21.5	22.0	
M^3 antero-posterior diameter.....	12.5	13.5	
M^3 transverse diameter..... .	18.0	19.0	

The Field Museum specimens from Lake Colhué-Huapí agree fairly well with this description and with the figures given. There is a certain amount of variation shown, but as stated above, we consider it to be entirely within the limits of a single species. The specific determination, however, is tentative and must await redescription of the original specimens for confirmation.

Localities. Ameghino has given no localities for his specimens. P13309 and P13528 were collected by Messrs. G. F. Sternberg and C. Harold Riggs south of Kilometer 145 near Lake Colhué-Huapí. P13296 was found by Mr. Sternberg at the south end of the lake near Kilometer 143.

Notes on the Entelonychia

Representatives of this suborder were abundant during the time covered by the deposition of the Casamayor formation and constituted, to judge from Ameghino's faunal list (1906, pp. 465–469), a fairly large element in the fauna. In the succeeding formations, however, they dwindled very rapidly both in numbers and importance, making up only a small fraction of the later faunas. Unfortunately, acquaintance with the early forms has hitherto been limited to Ameghino's brief descriptions and to fragmentary specimens obtained by a very few European and American museums. Knowledge of this important group has been largely based on *Homalodotherium*, one of the most peculiarly specialized of the extinct neotropical ungulates. This fact has not contributed to an adequate conception of the suborder as a whole.

In preparing the description of *Pleurostylodon* we have had frequent occasion to make comparisons with the excellent specimen of *Homalodotherium*, and with specimens of genera belonging to the Toxodonta and Typotheria, contained in the collections of the Field Museum. These comparisons have brought out a number of generalized characters common to the Entelonychia, which have, for the most part, been modified in the other two suborders. These generalized characters may be briefly summarized. *Dentition:* (1) The cheek teeth are comparatively low-crowned and hypsodonty

is not attained; (2) cement is never formed; (3) the transverse diameter of the upper molars is either in excess of the antero-posterior diameter (as in the majority of forms) or is approximately equal to it (as in *Homalodotherium*). In no case is there any considerable lengthening of the crown due to marked prolongation of the ectoloph posterior to the meta-cone; (4) every tooth is functional[1] and the only ones that undergo any appreciable change are the canines and the third incisors. *Skull:* (1) The auditory region is of a generalized type with a small epitympanic sinus, porus situated rather low on the side of the skull; (2) the skull is orthocephalic and the basicranial region is relatively long. *Feet:* These are adequately known in *Homalodotherium* only. In this genus, despite a great degree of specialization, there are five functional digits on each foot.

The summary given above indicates that the Entelonychia, although including highly specialized forms, were a group that retained much of the original notoungulate heritage, a view that has been previously expressed by Gregory (1910, p. 375), and mentioned by Simpson (1934, p. 13) in discussing the homalodotheres. The Toxodonta and Typotheria include more adaptive forms in which habitus characters have affected the ancestral heritage to a greater extent. Inability to compete successfully with the more progressive members of these two suborders was probably a major factor in the early extinction of the Isotemnidæ. The peculiar specializations of the homalodotheres were almost certainly correlated with fossorial feeding habits. In this field of activity these animals appear to have had no competitors which may account for their survival so long after the disappearance of the iso-temnids.

SUBORDER TYPOTHERIA ZITTEL

INTERATHERIIDÆ

The family Interatheriidæ has not hitherto been reported from the Casamayor formation but it is proposed to place in

[1] The only exception known to us is *Chasicotherium* of the Homalodotheriidæ, a genus from the lower Pliocene of Argentina recently described in a preliminary way by Cabrera and Kraglievich (1931, p. 2). This form, the last recorded entelonychian, has lost the median incisors.

it the genus *Notopithecus*,[1] which was formerly the type genus of the Notopithecidæ. The transfer is based primarily on the position of the jugal, which is excluded from the vicinity of the orbit and restricted to the middle of the zygomatic arch, a feature highly characteristic of the Interatheriidæ (Sinclair, 1909, p. 2).

<div align="center">Notopithecus Ameghino, 1901.   Plate V, figs. 2–5;
Text fig. 3</div>

The specimens at hand belonging to this genus are three in number, the palatal portion of a skull, P13298, with part of one arch and the cheek dentition, including P^2–M^3, and two incomplete mandibles, P14718 and P14719, which, between them, exhibit the complete lower dentition. The species of *Notopithecus* are about one-third smaller than *Protypotherium prærutilum* Ameghino, of the Santa Cruz.

<div align="center">THE SKULL (Plate V, figs. 4, 5)</div>

An incomplete specimen, P13298, comprising palatines, part of the palatal region of the right maxillary, and a portion of the right zygomatic arch is the only part of a skull in the collections. This fragment, small as it is, proves to be important, as it provides definite evidence upon which *Notopithecus* may be referred to the Interatheriidæ.

No maxillo-jugal suture can be detected in the preorbital region, the maxillary apparently forming the anterior rim of the orbit and also that part of the arch which is preserved. The zygomatic process shows a very distinct sutural area on its external side which could articulate with no element except a reduced jugal, such as characterizes *Protypotherium* and *Interatherium*. This arrangement of the facial bones

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[1] When this description was written we considered, following Ameghino, that the species described below belonged to the genus *Adpithecus*. Dr. Simpson, however, kindly informed us (letter to E. S. Riggs, November 9, 1932) that *Adpithecus* is a synonym of *Notopithecus*. The family Notopithecidæ therefore, according to our views, becomes synonymous with the Interatheriidæ. It is not by any means certain, however, that all the genera placed by Ameghino in the Notopithecidæ can be referred to the Interatheriidæ. This confusion is most unfortunate, but as we are in no position to settle it the matter must be left open pending Dr. Simpson's revision of the fauna.

occurs, so far as is at present known, in no other group of indigenous South American ungulates. The infraorbital foramen is large and situated above the third premolar while the anterior rim of the orbit is over the fourth. The palatines are constricted by deep notches immediately posterior to the last molars, as in *Protypotherium*, but the anterior border of the posterior nares is further forward than in that genus.

THE MANDIBLE (Plate V, figs. 2, 3)

The horizontal ramus (described from P14718) is the only part of the jaw that is preserved. The two rami are completely fused, showing no trace of a suture, the symphysis is shallow, and the ramus is deeper at the posterior end. The ventral border is convex but shows no indication of the rather abrupt prominence below M^3 which is so conspicuous a feature of the Santa Cruz genus *Interatherium*.

THE DENTITION

Both upper and lower dentitions are brachyodont, complete, and in series. There are some differences from the Deseado and later interatherids but these appear to be such as would be expected in a related but considerably earlier form.

Upper dentition (Plate V, figs. 4, 5).—The upper incisors, canines and first premolars, as described and figured by Schlosser in Zittel's text book (1923, p. 607, fig. 750), are simple, rather trenchant teeth with a slight median vertical groove on both labial and lingual faces. I^1 is the largest of the series. The others increase in size posteriorly to P^1 which is but little smaller than the first incisor. The first premolar is single-rooted. The posterior extremity of each tooth very slightly overlaps the anterior extremity of the one following. These teeth are shorter crowned than the corresponding ones in *Protypotherium*. I^1 and I^2 are relatively smaller than in that genus. P^1 is incisiform in *Notopithecus*, premolariform in *Protypotherium*. The second premolar in the Field Museum specimen of *Notopithecus* is longer antero-

posteriorly than transversely, the outline of the tooth is roughly triangular, the ectoloph is undulating and there are no cingula. The paracone is prominent and there is a conspicuous parastyle, the two being separated by a rather shallow, vertical groove. The protocone is large, central in position and connected to the parastyle by a long, oblique protoloph, and to the posterior extremity of the ectoloph by a shorter metaloph. A fairly deep central fossa is enclosed. P^3 is a considerably larger tooth than P^2 and differs in proportions in that the transverse diameter is somewhat in excess of the antero-posterior. This condition prevails in the rest of the premolar-molar series with the exception of M^3 in which the two diameters are approximately equal. The parastyle is larger than that on the second premolar, and the vertical groove separating it from the paracone is deeper and more prominent. The protoloph is long, oblique and slightly undulating; an anterior cingulum is present but is not well developed. A rather well developed and high posterior cingulum was undoubtedly present but on the specimen at hand this element has become joined by wear to the metaloph. The antero-external angle of P^3, and also that of the succeeding premolar and molars, slightly overlaps the tooth in front. The fourth premolar more nearly resembles the molars in general form than does P^3. It is considerably larger, subquadrangular in outline, and has a relatively greater transverse diameter. In structure it is very similar to the preceding tooth, the only appreciable difference being that the protoloph is rather less oblique.

The *upper molars* are rather sharply distinguished from the premolars by their larger size, their quadrangular outline, the presence of a postero-internal cusp (except on M^3), a more prominent metacone, and the vertical groove between the parastyle and paracone, which is much shallower than on the premolars, as is also the case in *Protypotherium*. On M^1 the transverse diameter is considerably in excess of the antero-posterior, the anterior cingulum is low and little developed, and no trace remains of the posterior, as on the premolars.

The second molar is the largest of the series and is distinguished from the first by its relatively greater antero-posterior diameter and by a deeper groove on the lingual side between the protocone and the postero-internal cusp. This groove is, however, by no means deep on M^2 and hardly noticeable at all on M^1. This, together with the position of the postero-internal cusp which is situated on the posterior slope of the protocone and closely connected with it, has led the writers to suspect that, as on the molars of *Notostylops*, this cusp is a pseudohypocone. This belief receives support from the fact that the entoconid of the lower molars shears between the protocone and the supposed pseudohypocone. The third molar is slightly smaller than the second and has approximately equal antero-posterior and transverse diameters. The postero-internal cusp appears to be lacking, as the protocone slopes evenly upward to join the posterior cingulum without showing a trace of any elevation which might be interpreted as the cusp in question. The anterior cingulum is low and little developed. Traces of the posterior may be seen on M^2 of the right side in the small areas of enamel that are reflected over upon the grinding surface.

Ameghino has figured an upper first molar of *N. secans* (1904 *b*, p. 178, fig. 233) which is less abraded than those of the specimen under consideration. On this tooth the posterior cingulum is still distinct from the rest of the grinding surface, and the structure of the central valley is fairly clear. An antecrochet, joins a crista from the ectoloph to enclose an antero-external fossette; a second crista and a crochet from the metaloph unite to isolate a postero-external fossette. From the combined crista and crochet a small spur extends antero-internally into the valley. It may be stated, judging from the arrangements of the fossettes on the grinding surfaces, that the central valley structure of the molars, and also of the premolars, of the specimen at hand (Plate V, fig. 4) was essentially similar to that of the tooth figured by Ameghino, with, possibly, some minor variations on certain teeth. It will be apparent from the description that the upper molar

pattern of this genus is essentially similar to that of the Entelonychia. The same is true for other early typotheres figured by Ameghino (1904 b).

Lower dentition (Plate V, figs. 2, 3; Text fig. 3). The following description is based upon the two mandibular rami previously mentioned. Specimen P14718 (Plate V, fig. 3) has lost the crowns of the first incisors, part of the crown of the fourth premolar and the third molar. Specimen P14719 (Text fig. 3) has the series complete from the second premolar to the third molar inclusive. Both specimens are from young individuals which makes it possible to describe the crown structure in detail.

The *incisors* are inclined forward, almost to the same extent as in *Protypotherium*. In structure they are rather simple trenchant teeth, increasing in size from $I_{\overline{1}}$ to $I_{\overline{3}}$ as in *Protypotherium*. The crown of $I_{\overline{1}}$ is missing; $I_{\overline{2}}$ and $I_{\overline{3}}$ are both rather deeply grooved on their lingual faces, the grooves imparting a bilobed appearance. Each incisor overlaps the succeeding tooth as does the canine also. In the essential features of structure and proportions, the incisors of *Notopithecus* are similar to those of *Protypotherium* as described by Sinclair (1909, p. 161), differing chiefly in being shorter crowned. The canine is incisiform in structure and smaller than $I_{\overline{3}}$. In *Protypotherium* these two teeth are subequal.

In their progressive complexity from $P_{\overline{1}}$ to $P_{\overline{4}}$ the premolars of *Notopithecus* demonstrate in a most striking and welcome manner the evolution of the typotherian lower molar. $P_{\overline{1}}$ is a narrow and rather simple tooth which resembles the incisors and canines, but anticipates the complex molars in its fundamental structure. It is a cutting tooth with an irregular edge, composed of two large cusps, and a smaller one. One of these appears at the anterior extremity, a second at the middle, and a third, smaller one at the posterior margin of the cutting edge. The anterior and central cusps are joined by an external crest. The posterior is joined by a crest to the inner side of the central cusp. The anterior cusp is the paraconid, the central the

protoconid, with which the metaconid is connate, and the posterior the hypoconid (Text fig. 3).   There is a shallow, vertical antero-internal groove between the paraconid and the protoconid, a very slight postero-internal one between the proto-metaconid and the hypoconid, and an external one between the protoconid and the hypoconid.   The internal grooves are the homologues of the anterior and posterior valleys of the typical notoungulate molar; the external groove is the one separating trigonid and talonid on the labial side. The important developments that take place on the succeeding premolars, as they become progressively molariform, are the increase in size of the talonid which becomes larger from tooth to tooth, the appearance and upgrowth of the
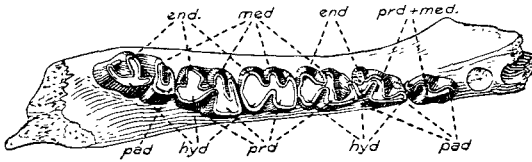
TEXT FIG. 3.   *Notopithecus secans* (Ameghino).   Crown view of right ramus with $P_{\overline{2}}-M_{\overline{3}}$, $x_{\overline{1}}^{2}$.   P14719.

Abbreviations: end., entoconid; hyd., hypoconid; med., metaconid; pad., paraconid; prd., protoconid.

entoconid, the progressive widening of the teeth and the divergence of the metaconid from the protoconid to form the metalophid.   These changes, both in structure and proportion, are extremely well shown on the teeth described below.

The second premolar closely resembles the first, differing from it in a few slight but significant features.   It is considerably larger than the preceding tooth in all dimensions. The metaconid, although ver small, is distinct from the protoconid; the heel is slightly longer and curved towards the lingual side.   On P14718 (Plate V, fig. 3) this curved portion is cuspidate.   The third premolar is considerably more advanced than either of its predecessors.   It is broader throughout in proportion to its length and the metalophid is enlarged transversely by the increase in size of the metaconid.   The

anterior portion of the trigonid is widened by the addition of
a ridge which runs from the antero-internal angle of the tooth
to a point about halfway up the paraconid. The talonid is
very much broadened by the addition of the entoconid (the
posterior pillar of the notoungulate lower molar) which
appears for the first time in the posterior valley between the
metaconid and the posterior extremity of the talonid. A
hypoconulid cannot be detected if present being probably
indistinguishably fused in the lophid of the talonid. The
fourth premolar is very similar to the molars, the chief
distinction being that the trigonid is slightly longer antero-
posteriorly than the talonid, whereas on the first and second
molars the talonid is slightly the longer of the two. Advances
in structure over that of the preceding tooth are important
but they are advances of degree and not of kind, as all the
elements of the crown are present on $P_{\overline{3}}$. Premolar $_{\overline{4}}$ is
very little longer than its predecessor but is wider throughout.
The trigonid is slightly reduced in length, while the talonid
is elongated and also transversely enlarged. The ridge on
the anterior extremity of the tooth is better developed than
that of $P_{\overline{3}}$, is united to the tip of the paraconid and forms the
anterior horn of the trigonid (anterior crescent of some
authors). The metalophid has been considerably widened
and the metaconid is now a conspicuous cusp on the ligual
side of the tooth and higher than the protoconid. The ento-
conid in this tooth is of considerable size and almost com-
pletely fills the posterior valley. The crista obliqua, instead
of joining the trigonid at the metaconid, now joins it midway
between the latter cusp and the protoconid, an important
structural advance.

From the above account of the progressive complication
of the premolars of *Notopithecus* it would appear that the
paraconid and the incipient heel were first differentiated from
the protoconid. The trigonid was then completed by the
separation of the metaconid, after this the enlargement of the
talonid and the addition of the entoconid followed. The
development of the metaconid from tooth to tooth is not

particularly well shown in the specimens of *Notopithecus* at hand. It appears to have been subordinated in the meta- lophid and to have become conspicuous only on $P_{\overline{4}}$. On the lower premolars of an undetermined, but evidently closely related typothere from the Casamayor beds at Punta Casa- mayor (P13439), the development of this cusp is much clearer as it remains distinct from, and posterior to, the protoconid throughout the premolar series (Text fig. 4).
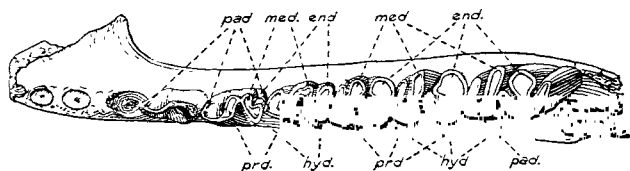
TEXT FIG. 4.   Gen. et sp. indet.   Crown view of left ramus with $P_{\overline{2}}$–$M_{\overline{3}}$, $\times\frac{2}{1}$. P13439.
Abbreviations as in Text fig. 3.

The *lower molars*. $M_{\overline{1}}$ differs very little from the last premolar. The trigonid is proportionately a little shorter antero-posteriorly and also somewhat wider than the talonid. The latter, in correlation with the reduction of the trigonid, is a trifle longer proportionately than that of $P_{\overline{4}}$. The slight decrease in size of the trigonid is brought about by the closer approximation of the anterior horn (paraconid + anterior ridge) to the metalophid or posterior horn (protoconid + metaconid), with the result that the anterior valley on the lingual side of the tooth undergoes some reduction. The paraconid is brought into closer contact with the protoconid, the two forming a stout pillar on the external side of the trigonid. The reduction in this genus is not carried so far as in the molars of *Notostylops*, or of most toxodonts and ente- lonychians in which the paraconid is possibly suppressed entirely [1] or at any rate subordinated more than appears to

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[1] It is of interest that in the members of the earliest notoungulate family at present known, the holarctic Paleocene and lower Eocene Arctostylopidæ, the trigonid of the lower molars is more reduced than in any of the later South American genera. (Matthew, 1915, pp. 429, 431; Matthew and Granger, 1925, p. 2.)   In fact, Simpson (1934, p. 10) has given the extreme reduction of the anterior wing of the trigonid as a character of the Notioprogonia.

be the case in *Notopithecus*. The second molar is very slightly larger than $M_{\overline{1}}$ and shows an advance over that tooth in the antero-posterior enlargement of the entoconid which sends forward a spur toward the metaconid, thus tending to close the posterior valley. This spur, together with the crista obliqua, isolates a small fossette at the anterior extremity of the talonid (Plate V, fig. 3). Despite its enlargement, however, the entoconid does not lose its high, conical shape. The last molar (Text fig. 3) is the largest of the series, the increase in size having taken place entirely in the talonid, the lophid of which is considerably prolonged posterior to the entoconid, as in *Notostylops*. A low crest connects the latter cusp with the posterior extremity of the lophid, enclosing a shallow pit at the postero-internal angle of the tooth. The entoconid does not send a spur forward as it does on $M_{\overline{2}}$. The tendency of the entoconid of the last two molars toward filling up the valley on the lingual side of the talonid illustrates in a satisfactory manner the way in which this valley was closed in the later members of the Interatheriidæ and in other families of the suborder.

The lower premolar-molar dentition of *Notopithecus* is of interest from several points of view—morphologic, taxonomic and phylogenetic. The morphologic importance of these teeth in demonstrating the development of the typotherian lower molar has been described above. The taxonomic and phylogenetic significance lies in the tendencies of the teeth toward the interatherid type as shown by the later members of this family. In the crown pattern, they agree closely with toxodonts and entelonychians, but in form and proportions they resemble such genera as *Interatherium* and *Protypotherium* of the Santa Cruz. If the trigonid and talonid of the two anterior lower molars of *Notopithecus* are considered in their entirety, that is, in their form and proportions at the base of the crown, it becomes apparent that they roughly resemble two subequal triangles with apices pointing anteriorly. This is precisely the appearance of slightly worn lower molars of later representatives of the Interatheriidæ.

In these later hypsodont genera the crown pattern is shallow and the only structures that remain to demarcate the trigonid and talonid are the median grooves on the labial and lingual sides of the teeth, structures which persist through almost the entire height of the crown.   In *Notopithecus* these grooves extend nearly to the base of the teeth and so are deeper than the other crown elements.   It seems probable that, as the teeth of the succeeding members of the family became hyposodont, the grooves lengthened with the crown while the other structures of the grinding surface did not.

From the foregoing observations it may be said that no feature in the lower dentition of the genus under consideration in any way prevents its reference to the Interatheriidæ; on the contrary, certain points of structure indicate that this form is, structurally, an ideal ancestral type for the later members of the family.

<div align="center">RELATIONSHIPS</div>

The restriction of the jugal of *Notopithecus* to the zygomatic arch is direct evidence that the genus is a member of the Interatheriidæ.   The structure of the dentition, especially of the lower molars, offers considerable evidence in favor of the same conclusion.   Ameghino (1905, p. 419) stated that the astragali of *Protypotherium* and *Adpithecus* (= *Notopithecus*) were of the same type, and (p. 417) that the latter genus probably represented the starting point of the Protypotheriidæ (= Interatheriidæ).   It seems probable that other genera of Ameghino's families of Casamayor typotheres, when better known, will have to be transferred to the Hegetotheriidæ or the Interatheriidæ.   The jugal of *Notopithecus*, judging from the specimen at hand, appears to be as highly specialized as in the Santa Cruz members of the family.   The fact that this very characteristic feature is present in a Casamayor genus indicates that the Interatheriidæ, and probably the other typotherean families also, had begun to diverge at a time prior to the deposition of the Casamayor beds.   If,

as Schlosser has considered, this horizon is of upper Eocene age, the earlier divergence is not surprising.

The complete and brachyodont dentition of *Notopithecus* does not display the somewhat rodent-like adaptations of the later members of the suborder and the same probably holds true of other Casamayor typotheres. Progressive characters such as hypsodent teeth and enlarged incisors were later developments. This is of interest in view of the fact that *Notostylops*, which also appears to have been specialized along rodent-like lines, was abundant in the Casamayor fauna. The members of the Notostylopidæ evolved an enlarged pair of incisors but did not acquire hypsodonty. It appears that, in the early Tertiary of South America, there was an adaptive succession of ungulates which, to some extent, paralleled rodents and occupied their place in the fauna. The first group to develop along these lines seems to have been the brachyodont Notostylopidæ, which was replaced by the hypsodont, and probably better adapted, typotheres. True rodents made their first appearance, so far as is now known, in the Deseado but by that time the typotheres were fully specialized and successfully held their own.[1] In Casamayor times, if *Notopithecus* is a reliable criterion, the typical typotheres were entering upon their dental specialization while the Notostylopidæ were still numerous.

<div align="center">SPECIES</div>

Six species have been described by Ameghino (including three which he referred to *Adpithecus*). Of the specimens at hand, the skull fragment and the mandible P14719 are referred to *N. secans* (Ameghino, 1901, p. 355), mandible P14718 to *N. reduncus* (Ameghino, 1902, p. 8).

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[1] The later, *i.e.* Pliocene and Pleistocene, rodents provide an interesting postscript. During these periods gigantic genera, *Eumegamys*, etc., came into existence and very probably competed with the ungulates, a state of affairs that has existed in no other part of the world as far as the geologic record at present shows. Thus, notoungulate history, which opened with small members of the order simulating and then competing with rodents, ended with giant rodents assuming the proportions of the larger ungulates and doubtless competing with them.

MEASUREMENTS

	N. secans P13298 mm.	N. secans P14719 mm.	N. reduncus P14718 mm.
P^{2} antero-posterior diameter........	3.0		
P^{2} transverse diameter......	3.0		
P^{4} antero-posterior diameter..........	3.0		
P^{4} transverse diameter..............	4.0		
P^{4} antero-posterior diameter.....	3.5		
P^{4} transverse diameter......	4.5		
Molar series, length.................	11.5		
M^{1} antero-posterior diameter......	3.5		
M^{1} transverse diameter..........	5.0		
M^{2} antero-posterior diameter...	4.0		
M^{2} transverse diameter.....	5.0		
M^{3} antero-posterior diameter............ . ..	4.0		
M^{3} transverse diameter.....................	4.0		
$I_{\overline{1}}$ antero-posterior diameter [1]....			1.5
$I_{\overline{1}}$ transverse diameter [1].....................			1.5
$I_{\overline{2}}$ antero-posterior diameter.....			2.0
$I_{\overline{2}}$ transverse diameter.....			1.5
$I_{\overline{3}}$ antero-posterior diameter....			3.0
$I_{\overline{3}}$ transverse diameter..................			2.0
Canine antero-posterior diameter.......			2.5
Canine transverse diameter.........			1.5
Premolar series, length.................... ...			13.5
$P_{\overline{1}}$ antero-posterior diameter..................			3.0
$P_{\overline{1}}$ transverse diameter......................			1.7
$P_{\overline{2}}$ antero-posterior diameter.................		3.2	3.5
$P_{\overline{2}}$ transverse diameter......................		2.2	2.0
$P_{\overline{3}}$ antero-posterior diameter..................		3.5	3.5
$P_{\overline{3}}$ transverse diameter.........		2.5	—
$P_{\overline{4}}$ antero-posterior diameter.....		4.0	4.0
$P_{\overline{4}}$ transverse diameter.......		2.7	2.5
Molar series, length........		13.5	—
$M_{\overline{1}}$ antero-posterior diameter.................		3.7	3.7
$M_{\overline{1}}$ transverse diameter.................		2.7	2.5
$M_{\overline{2}}$ antero-posterior diameter.................		4.2	4.5
$M_{\overline{2}}$ transverse diameter.....		3.0	3.0
$M_{\overline{3}}$ antero-posterior diameter.................		6.0	—
$M_{\mathbf{3}}$ transverse diameter.....................		3.0	—

[1] Measurements taken from the root.

The measurements given by Ameghino for *N. secans* (1901, p. 356) are: length of the upper dentition 33 mm., of the skull 67 mm., depth of the mandible under $M_{\overline{1}}$, 11 mm. The only measurement given for *N. reduncus* (1902, p. 8) is the combined lengths of the first and second lower molars, which total 9 mm.

Localities.—All the specimens of this genus here described were collected by Mr. G. F. Sternberg at the south end of Lake Colhué-Huapí. No localities are given for the specimens described by Ameghino.

REFERENCES

AMEGHINO, F.
    1897. Mammifères crétacés de l'Argentine. Deuxième contribution à la faune mammalogique des couches à *Pyrotherium*. Bol. Inst. Geogr. Arg. **18**, pp. 405–517.
    1901. Notices préliminaires sur des ongulés nouveaux des terrains crétacés de Patagonie. Bol. Acad. Nac. Sci. Córdoba, **16**, pp. 349–429.
    1902. Notices préliminaires sur des mammifères nouveaux des terrains crétacés de Patagonie. Bol. Acad. Nac. Sci. Córdoba, **17**, pp. 5–73.
    1903. Nuevas especies de mamíferos cretáceos y terciarios de la República Argentina. An. Soc. Cient. Argentina, **56**, pp. 193–208.
    1904 *a*. The same paper continued. Ibid., **57**, pp. 162–175, 327–341; **58**, pp. 35–41, 56–71, 182–192, 225–291.
    1904 *b*. Recherches de morphologie phylogénetique sur les molaires supérieures des ongulés. An. Mus. Nac. Buenos Aires, (3), **3**, pp. 1–541.
    1905. La perforación astragaliana en los mamíferos no es un caracter originariamente primitivo. An. Mus. Nac. Buenos Aires, (3), **4**, pp. 349–460.
    1906. Les formations sédimentaires du crétacé supérieur et du tertiaire de Patagonie avec un parallèle entre leurs faunes mammalogiques et celles de l'ancien continent. An. Mus. Nac. Buenos Aires, (3), **8**, pp. 1–568.
GAUDRY, A.
    1904. Fossiles de Patagonie. Dentition de quelques mammifères. Mém. Soc. Geol. France, Paléontologie, **12**, mém. no. 31, pp. 1–28.
GREGORY, W. K.
    1910. The orders of mammals. Bull. Amer. Mus. Nat. Hist., **27**, pp. 1–524.
    1920 *a*. On the structure and relationships of *Notharctus*, an American Eocene primate. Mem. Amer. Mus. Nat. Hist., N.S., **3**, pp. 49–243.
    1920 *b*. Studies in comparative myology and osteology; No. IV. A review of the evolution of the lachrymal bone of vertebrates with special reference to that of mammals. Bull. Amer. Mus. Nat. Hist., **42**, pp. 95–263.
LOOMIS, F. B.
    1914. The Deseado formation of Patagonia. Amherst, 1914, pp. i–xi, 1–232.
MATTHEW, W. D.
    1915. A revision of the lower Eocene Wasatch and Wind River faunas. Part IV. —Entelonychia, Primates, Insectivora (part). Bull. Amer. Mus. Nat. Hist., **34**, pp. 429–483.
MATTHEW, W. D. & GRANGER, W.
    1925. Fauna and correlation of the Gashato formation of Mongolia. Amer. Mus. Novit., No. 189, pp. 1–12.
OSBORN, H. F.
    1931. Titanotheres of ancient Wyoming, Dakota and Nebraska. U. S. Geological Survey, Monograph 55, 2 vols.
PATTERSON, B.
    1932. The auditory region of the Toxodontia. Geol. Ser. Field Mus. Nat. Hist., **6**, pp. 1–27.
    1934 *a*. Upper premolar-molar structure in the Notoungulata. Geol. Ser., Field Mus. Nat. Hist., **6**, pp. 91–111.

PLATE I

Notostylops murinus Ameghino.
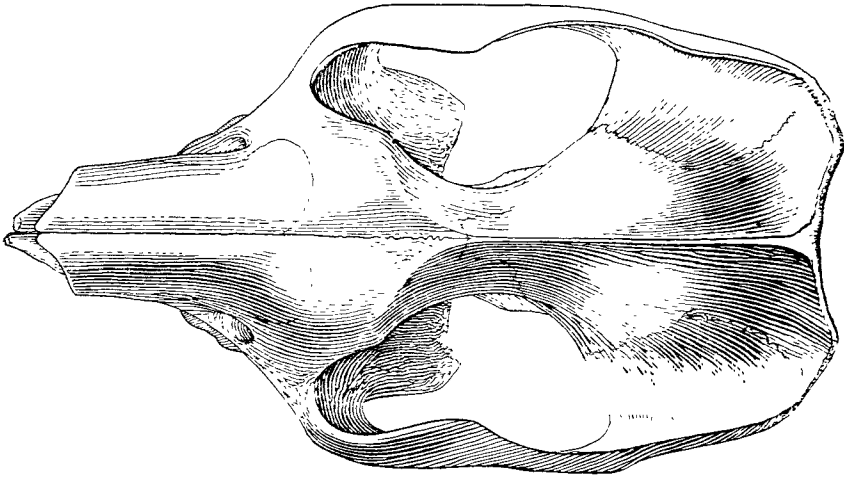
FIG. 1.   Skull, dorsal view, x⅓.
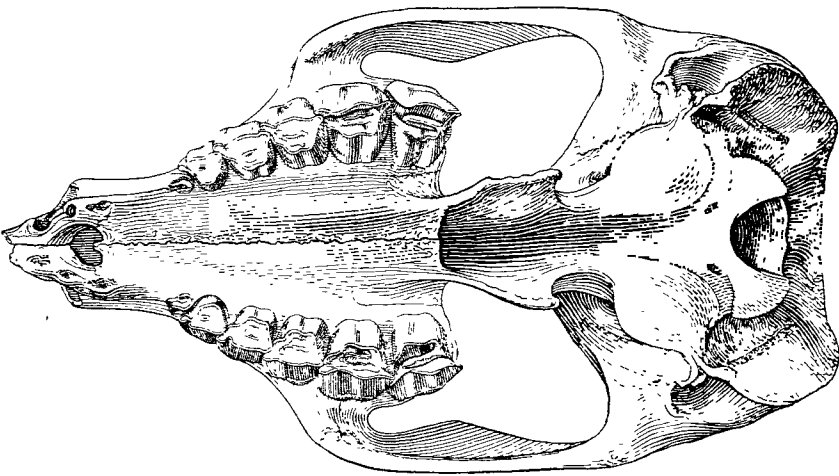
FIG. 2.   Skull, ventral view, x⅓.

Figures from specimen No. P13319, Field Museum.

The postorbital processes of the frontals, the anterior halves of the zygomatic arches, the condyles and the internal portions of the bullæ have been restored. The first four cheek teeth belong to the deciduous series.

PLATE II
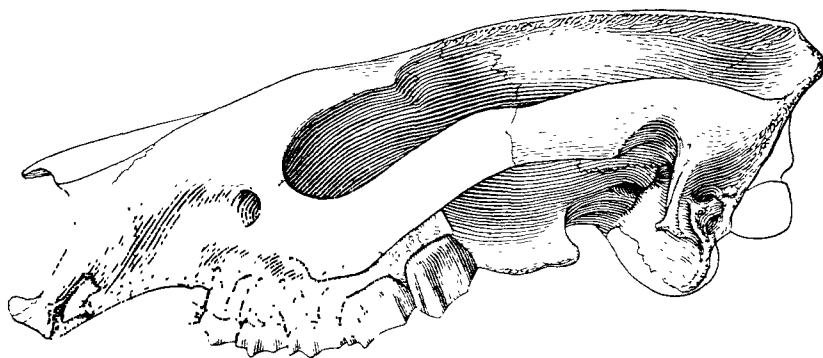
FIG. 1. *Notostylops murinus* Ameghino. Skull, lateral view, x¼. P13319.
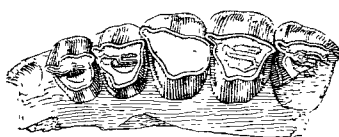
FIG. 2. *Notostylops murinus* Ameghino. P³–M³, crown view, x¼. P13299.
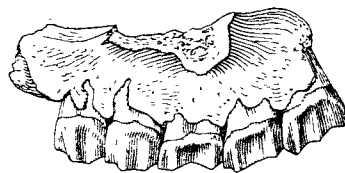
FIG. 3. *Notostylops murinus* Ameghino. P²–M³, lateral view, x¼. P13299.
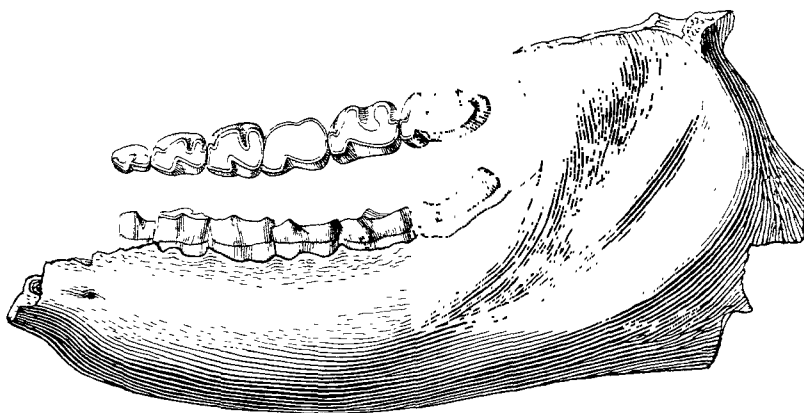
FIG. 4. *Notostylops murinus* Ameghino. Left mandible, lateral view; lower pre-molar-molar dentition, crown view, x¼. P13447.

PLATE III

Pleurostylodon (?biconus (Ameghino).
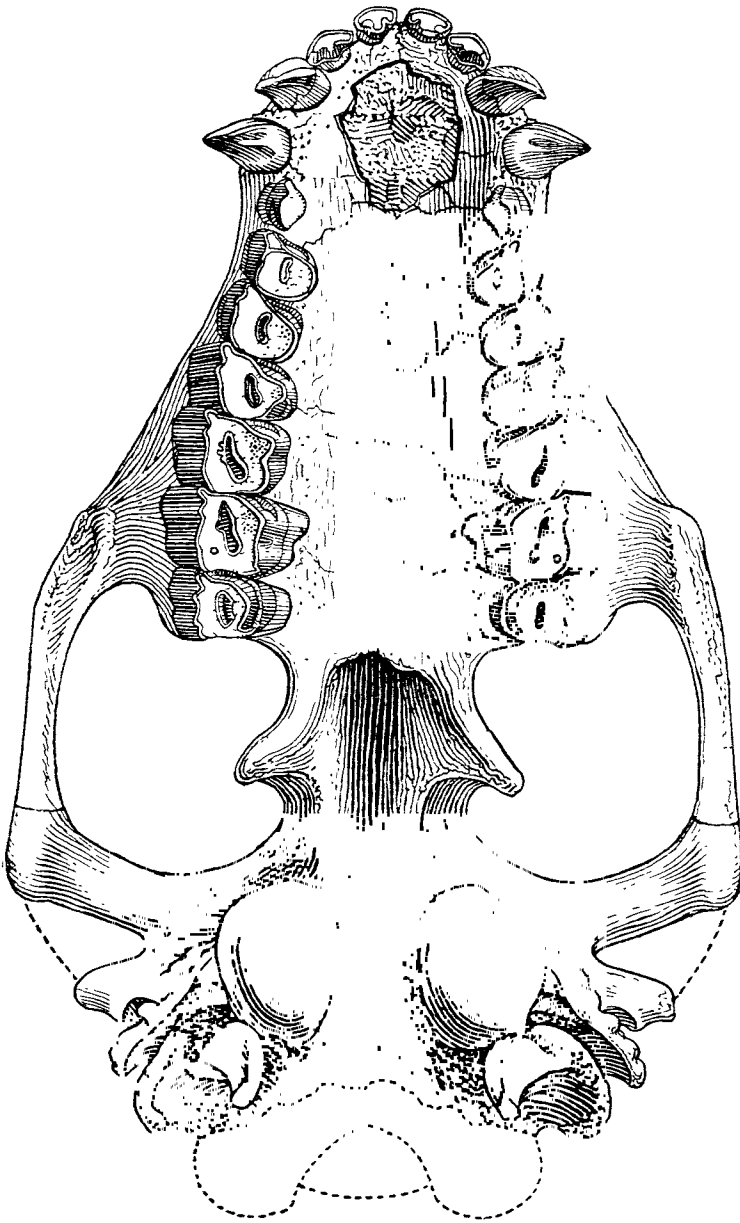
FIG. 1. Skull, ventral view, x¼. P13528.

PLATE IV

Pleurostylodon (?)biconus (Ameghino).
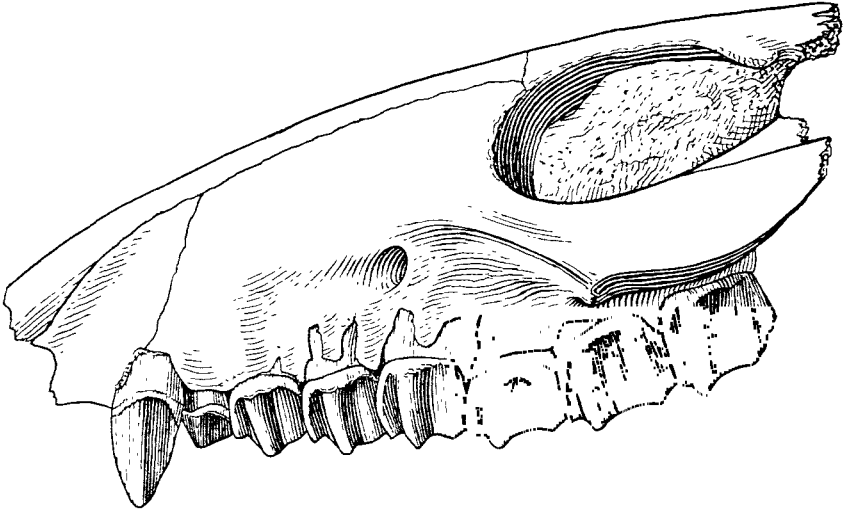
FIG. 1.   Facial region, lateral view, x$\frac{1}{1}$.
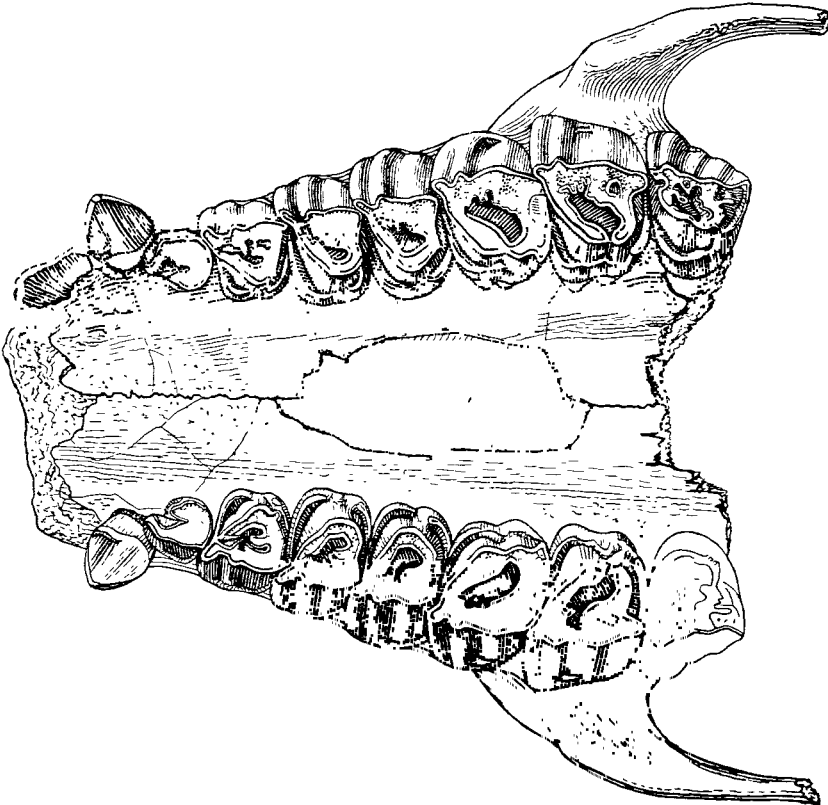
FIG. 2.   Palate, x$\frac{1}{1}$.

Figures from specimen No. P13296, Field Museum.

The specimen has been compressed dorso-ventrally and the distortion has not been corrected in the drawing.

PLATE V
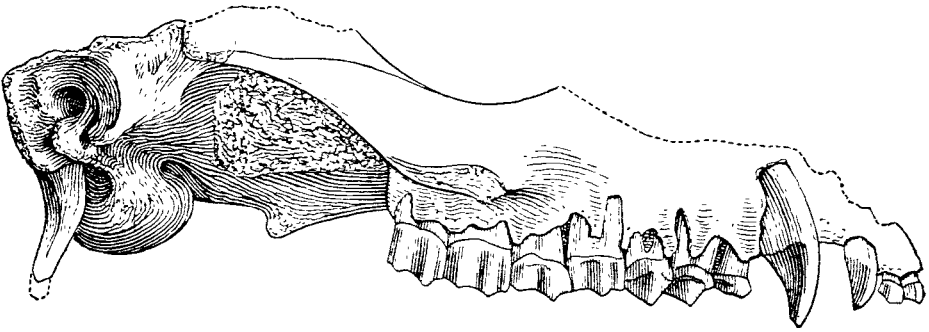
FIG. 1.   *Pleurostylodon (?)biconus* (Ameghino).   Skull, lateral view, x⅓.   P13528.
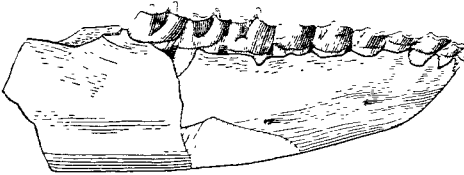
FIG. 2.   *Notopithecus reduncus* (Ameghino).   Right ramus mandibuli, lateral view, x¾.   P14718.

FIG. 3. *Notopithecus reduncus* (Ameghino).   Right ramus mandibuli, crown view, x¾.   P14718.
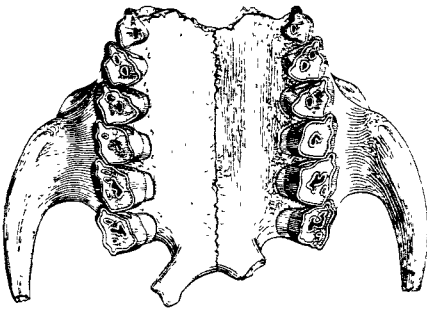
FIG. 4.   *Notopithecus secans* (Ameghino).   Palate, x⅓.   P13298.
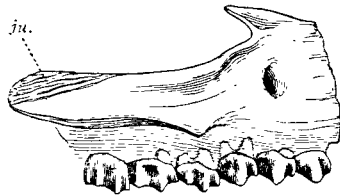
FIG. 5.   *Notopithecus secans* (Ameghino).   Right maxillary, lateral view, x⅓ P13298.
ju., sutural area for the jugal.

1934 *b*. Cranial characters of *Homalodotherium*. Geol. Ser. Field Mus. Nat.
        Hist., **6**, pp. 113–117.
SCHLOSSER, M.
    1923. Mammalia *in* Zittel's Grundzüge der Palaontologie, II Abteilung: Ver-
        tebrata. R. Aldenbourg, München and Berlin.
SCOTT, W. B.
    1912. Toxodonta of the Santa Cruz beds, Entelonychia of the Santa Cruz Beds.
        Rep. Princeton Univ. Exped. Patagonia, **6**, pp. 111–300.
    1930. A partial skeleton of *Homalodontotherium*. Field Mus. Nat. Hist. Geol.
        Mem., **1**, pp. 1–34.
SIMPSON, G. G.
    1932. Skulls and brains of some mammals from the *Notostylops* beds of Patagonia.
        Amer. Mus. Novit., No. 578, pp. 1–11.
    1933 *a*. Braincasts of *Phenacodus*, *Notostylops* and *Rhyphodon*. Amer. Mus.
        Novit., No. 622, pp. 1–19.
    1933 *b*. Braincasts of two typotheres and a litoptern. Amer. Mus. Novit., No.
        629, pp. 1–18.
    1934. Provisional classification of extinct South American hoofed mammals.
        Amer. Mus. Novit., No. 750, pp. 1–21.
SINCLAIR, W. J.
    1909. Typotheria of the Santa Cruz beds. Rep. Princeton Univ. Exped.
        Patagonia, **6**, pp. 1–110.
WINGE, H.
    1905. Jordfunde og nulevende Hovdyr (Ungulata) fra Lagoa Santa, Minas
        Geraes, Brasilien med udsigt over Hovdyrenes indbyrdes Slaegtskab.
        E. Museo Lundii, **3**, Kjobenhavn, pp. i–lv, 1–321.

PENROSE MEMORIAL LECTURE

IS THE UNIVERSE RUNNING DOWN?

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(Read April 18, 1935)

WHEN the American Philosophical Society did me the honor of inviting me to deliver the Penrose Memorial Lecture, I was told that I was to speak upon the Second Law of Thermodynamics; and, on enquiry, I found that I was also expected to make it intelligible to those members of the Society and their friends who are not mathematicians or physicists. On learning this, I bethought me of the medieval custom of trial by ordeal in which the culprit could only win freedom by performing some painful and impossible act. I began to wonder what sin I had committed, who might be my heartless enemy who was thirsting for my blood, and in what unpleasant form he might be hoping to take it if I failed. Then, some element of mercy for me seemed to have penetrated the hearts of my judges; or, perhaps, was it mercy only for the audience, to spare them the horrible spectacle of my torments during the ordeal? It was suggested that the title be changed to "Is the Universe Running Down?" The change has been made; but you will get the same speech in spite of that.

If I should be asked to give a brief illustration of what, in its usual interpretation, the second law of thermodynamics means to the world of inanimate matter; and if, in order to bring it home to your consciousness a little more vividly, I should be allowed to extend it beyond the scope of its legitimate application, but perhaps within the scope of its spirit, then to our universe, with its molecules and atoms of dead matter, with its worlds, its stars, and its galaxies rich in structure and in principles of control, I should add the world of animate beings, with all of its intricate laws of

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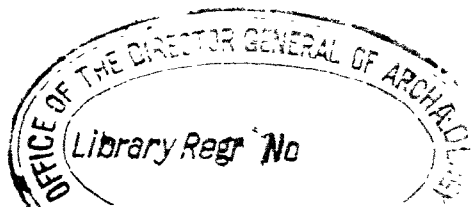
government and of social structure. Standing beside me
I should vision a cold and supercilious oracle who, in his
statements to me, symbolized what, for this combination of
animate and inanimate universes, would be the analogue of
what the second law of thermodynamics would have to say
for the inanimate universe alone. Let me cite, in the form
of a dream, my supposed conversation with this oracle who
guards within his consciousness the laws by which the universe
is governed.

In my dream I saw much sadness around me; and I
demanded of the oracle, "Can not the world be made better
and richer than it is?"

"No," said the oracle, "it is bound for the dogs."

"But," said I, "may not a revolution occur which will
improve the lot of those poor people whom I see yonder, and
the lot of humanity in general?"

"No," said the oracle, "a revolution might improve,
temporarily, the lot of the people you speak of, but it would
destroy civilization somewhere else to such an extent that
the world, or the universe as a whole, would be worse off
than it was before. Even the temporary improvement in the
people in whom you are interested would be but a passing
phase, and their ultimate fate would be, if anything, hastened
by their temporary good fortune."

"But," said I, "can matters never improve?"

"No," said the oracle, "they can only get worse in the
long run—a house can fall down, but it can never build itself
up again."

"But to pursue your own analogy about the house," said
I, "might not yon house in falling down fall upon that factory
over there, and, by hitting one of the machines, knock into place
a certain bolt which I happen to know was always out of place,
and which has so far prevented the machine from working.
If that machine were set working, might it not build another
house more beautiful and possessed of more intricate structure
than that which was destroyed?"

"Ah! my friend," replied the oracle, "there might have been a universe in which such a thing could happen, but in our universe, governed by the laws which I have written upon a scroll in my pocket, I can tell you that such a thing can never happen; or, at any rate, if it did happen, it would happen with a degree of rarity such as to render the thought of its occurrence of no significance." "But," the oracle continued, "Before we can continue this conversation with profit, we must pause and come to a little better agreement as to what it is we are talking about. You stated that the second house which was brought into existence by the fall of the first might be more beautiful than the first. Before I can talk with you, we must have some measure of structure or beauty. Now I, the oracle, have a measure of structure; and in terms of my measure, the net structure in the universe would be less after the first house had fallen down."

"But, my dear Oracle," I interposed, "your measure of structure may be a very foolish one; and, in terms of my human intuitions, the actual structural content and richness of the universe may increase while in terms of your measure it diminishes."

"To that I agree," replied the oracle. "But the significant thing is this: in terms of my measure of structure, everything that happens in the universe tends to decrease the structure. You and your fellow humans may disagree with me that the structure is really decreasing; but my continual decrease of structure leads to an end-point. I can tell you what that end-point will be, and even you and your fellow humans will agree that the end-point which I vision is the limit of chaos. I, the oracle, say that we are moving towards chaos continually. You may not agree with me as regards the "continually," because you may not agree with my measure of structure; but call my measure what you like—call it a figment of the oracle's imagination, if you will—provided only that you accept the doctrines embodied in the laws of the universe which I have in my pocket, you will have to conclude that the changes of the universe are towards an

end-point in which you yourself will admit that all structure
has vanished.   If you accept the doctrines to which I have
referred, we may not agree as to the way in which we are going
to the dogs, but we shall both have to agree that to the dogs
we finally go."

"And what," I demanded, "is this final state of the dogs
to which you refer?"

"It is one," he answered, "in which all men shall be equal.
There will be no kings, no presidents, no government.   All
men will be exactly alike.   There will be no criminals and
no very good men.   Nobody will have any ideas, and it will
be impossible for anybody to do anything which he has not
done before.   There will be nothing that anyone can do that
every other cannot do.   Nobody will have any ambitions or
regrets."

"Well," said I to the oracle, "at least we shall be safe,
secure, and stable."

"Yes," said the oracle, "you will be very stable—you
will be dead; for in this chaos, as I see it, your very life,
energy, and potentialities for all action will be shared with
so many things which now live not at all—with every grain
of sand on the sea shore—that the amount which will fall
to the lot of anyone of you will be small indeed." [1]

And then, in my despair, I implored the oracle to tell me
whether, consistent with holding to the doctrines contained
in the manuscript in his pocket which he seemed to value
so much, there might not be *some* way in which the chaos of
which he spoke might grow once more to order.

"Come," said he with a malicious laugh, "I will show you
the only way in which what you wish can be done."   And he
took me into a desert where there was nothing but barrenness
and sand.   "Let us wait a while," he said.   And as we waited
a storm arose, and the sand was blown hither and thither.

[1] The technical reader will here pardon the invocation of a sort of principle of
conservation of life which I have invoked into my analogy for purposes of illustration,
a principle, of course, intended to typify the conservation of energy in the inanimate
world.

When the storm was spent, I saw before me a little pile of sand which the storm had blown there.

"Look at that pile of sand," said the oracle. "Do you think it very beautiful?"

"No," I replied, "it is just a pile of sand."

"Let us wait for another storm," said the oracle.

And we waited. Again the wind blew and the sand was scattered. When all was quiet once more, I saw before me another mound of sand. "What have you there?" said the oracle.

"I have a mound of sand," said I.

"Do you think it very beautiful?" asked the oracle.

"No," I replied, "it, also, is only a mound of sand."

"But," urged the oracle, "is it not of a shape different from the last?" I agreed that it was.

"Then let us wait for another storm," said the oracle.

"But," I protested, "what are we trying to do?"

"We are waiting," answered the oracle, "until, by accident, the storm will some day blow the sand into the form of a cathedral, and by accident blow from afar such ingredients as mixed with the rain shall produce the cement which by accident may fall in such places as are necessary to cement the cathedral together and make a permanent structure."

"But," I cried, "such a thing is impossible."

"No," the oracle said, "not impossible, but (and he became inexpressibly cynical) highly improbable."

And, as the oracle saw me meditating in sadness, he said, "Come, my friend, I will tell you why all this is so. Before the sand and dust which made this desert were here, they formed the parts of beautiful rocks, and, for all I know, cities and buildings. In this form they were part of a rich and beautiful structure. Why that structure existed, I do not know; but this I do know—that the number of ways in which the grains of sand and dust can be arranged into beautiful structures is infinitesimally small compared with the number of ways in which they can be arranged to produce no structure at all. Now the principles which I have in my pocket tell

me that while the laws of nature do not object to the existence
of beautiful structures if formed, they do not conspire to
produce them to the exclusion of others. They have no
preference; and when they get a chance to operate on a
structure and produce another, they give equal opportunity
to all structures, the beautiful and the barren. When they
first operate to change a structure they do not necessarily
produce complete chaos at once; but, little by little, they
work in that direction, and always waiting in the distance
of time are those structureless forms outnumbering im-
measurably all those with structure. These swarms of
barren forms await their share in what nature has to give them.
They await their turns to exist. Each of them awaits in
expectation for its little life. And, when nature has bowed
to their wishes, her chance to find a way back to order is
infinitesimal. She has left but the order of disorder. Change
she may indeed produce, but the new thing she creates has
but an infinitesimal chance of having any more form than
that which it replaced."

And now we must say goodby to our oracle. His purpose
has been to give us at the start of this lecture, and I fear well
into the heart of it, a faint preview of the kind of story which
it is our task to tell. We must return to the realities of
inanimate matter exclusively and speak in language ap-
propriate to the things which compose it. Before making
the transition, however, I should like to show a simple experi-
ment to illustrate the last remarks of our oracle.[1]

On the screen is a mechanical slide composed of red beads
and colorless beads. The red beads are at the bottom and
the colorless beads are at the top. For this reason the slide
has a kind of structure. I will rotate the slide a few times.
You will observe that the beads are now more mixed up. I
will continue the rotation and now, as you will observe, the
red and colorless beads are fairly evenly distributed. If I
rotate the slide a few more times, you will not doubt but that
the beads will then occupy positions entirely different from

[1] The nature of the experiment here shown will be sufficiently obvious from the text.

those which they occupy now. Yet, I suppose you would be very surprised if in that new arrangement we found all the red beads once more at the bottom and the colorless ones at the top. And yet, why should you be surprised, for I may as well tell you that that particular arrangement is as likely as any other one—the present one for example? You are surprised because, intuitively, you have sensed in this case the point which the oracle was trying to bring out. The number of ways in which the beads may be rearranged to look very much as they look now is enormously large compared with the number of ways in which they can be arranged with all the red beads at the bottom and the colorless beads at the top, in spite of the fact that the number of ways of producing different arrangements of that kind by interchanging the red beads among themselves, and the colorless beads among themselves, is very large. There is always a *chance* that when I rotate the slide a few times more I shall find all the red beads at the bottom and all the colorless ones at the top, but the chance is infinitesimally small. You may be interested in knowing what it is in the present instance. The slide contains 70 red beads and 70 colorless beads. I have calculated that if I go on mixing them and then examining the result, I shall have to go through the operation on the average about—and here I have no name for the number of times because it has 140 zeros after it—before realizing a case where all the red beads are once more at the bottom and all the colorless beads are at the top. It took me but few mixings to create disorder out of order, but to create order from disorder requires untold mixings. Wide and many are the roads which lead from order to chaos; but narrow and few are the paths from chaos to order, and few there be who find one.

The second law of thermodynamics had its origin in the study of heat. It was preceded by what is known as the first law of thermodynamics which is frequently regarded as an extension of the principle of the conservation of energy to those processes in nature which involve the production or

utilization of heat.   Those members of my audience who are
specialists in physics or allied fields will not require that I give
them a definition of the meaning of kinetic and potential
energy, and they will understand and forgive me. if, for the
benefit of the others, I speak rather naïvely about these
concepts where the naïvetés are more or less irrelevant, even
though I speak with sophistication in other parts of my
discourse where the matters concerned are significant.   It
will suffice then to say that a body, or a machine, or con-
traption or assemblage of contraptions possesses energy if it
possesses the power to impart motion to other bodies.   It
may possess energy in virtue of its own motion—kinetic
energy as we call it—for then by impact with other bodies it
may impart motion to them.   It may also possess energy on
account of its state, as is the case with a coiled spring which,
though quiescent, shows when released that it possesses
very much power to communicate motion to other bodies.
The spring possesses potential energy.   In the general case,
any system taken at random possesses both of these kinds
of energy—kinetic and potential.   When the physicist has
sensed in the crude form new concepts such as kinetic and
potential energy, he proceeds as quickly as possible to invent
some "yard stick," in terms of which he can make measure-
ments of them, just as a golfer proceeds to measure the
efficiency of different players by measuring for them some-
thing which he calls a "handicap."   Now in terms of the
measurements which the physicist had invented for kinetic
and potential energy, it turned out that most of the simple
processes of nature went on in such a way that if we con-
sidered the system as a whole, its potential energy might
change into kinetic energy or vice versa, but the sum of the
two always remained the same.   The total energy was
conserved.   An example is to be found in a mass tied to the
center of a horizontal piece of elastic.   If the mass is pulled
to the right, in the direction of the length of the elastic, and
if it is then released, it will vibrate back and forth across its
mid-point.   At the instant when the mass is at its extreme

right, and is just about to reverse its direction of motion, its velocity is zero; and, it has no kinetic energy, although at this instant the elastic is stretched to its maximum degree, and possesses much potential energy. On the other hand, when the mass is passing through its mid-position, the elastic is unstretched, and so possesses no potential energy; but the mass is now moving at its fastest speed and possesses much kinetic energy. In the intermediate positions there is a mixture of kinetic and potential energies, but in the example quoted the sum of the two remains constantly the same. At least this would be so if there were no friction. But alas! as you well know, there is friction, and you know that, as a practical fact, the mass would not go on vibrating forever. The sum of the kinetic and potential energies—the total energy of the system—mass and elastic—would diminish with time. Now, it is possible for you to trace in a reasonable manner the loss of some of this energy, for the air is moved by the motion of the mass. But if you perform the experiment in a vacuum, you will still find that the motion of the mass will die down in time. You will attribute this fact, and quite correctly, to the friction in the elastic itself. But then, I begin to wonder whether the elastic has anything to show for this loss of energy which it has somehow or other demanded and collected in virtue of its friction. If I look at it at the end of the experiment, it will look just as it did before. If I examine it sufficiently carefully, however, I shall find that it has been slightly warmed. We say that heat has been produced in it by the friction. Now, one of the outstanding advances of the last century was made when it was realized that whenever energy, in the more obvious forms of observable kinetic and potential energy, appeared to vanish, heat was produced somewhere as a result; and, moreover, it was possible to derive a method for measuring this heat, independent of the way in which it was produced, and such that when measured in this manner the heat produced was the exact equivalent of the energy which appeared to have been lost. Before this time, heat had been thought

of as a kind of substance, a fluid which could be forced into or out of matter, and which was itself conserved and unconvertible into anything else. Now, however, the mind began to sense this apparently mysterious thing "heat" as really a thing of no mystery. It itself was merely a form of energy, and was, in fact, in large part nothing more than the kinetic energies of the individual molecules and atoms. When a system appeared to lose energy and so get hot, there was no real loss of energy. The energy of the big things of the system, the wheels and springs and masses, was simply transferred in part to the little things, the atoms and molecules, where it existed in the very definite form of their kinetic energy, for the most part, but in a form more difficult to get hold of and use than was the form in which it existed in the wheels of the machinery.

And so we started to look longingly at all the energy residing in apparently useless form in the atom and molecules. Could we not get it back again into the wheels of the machinery? It was not lost. There it was in the molecular motions. But must it exist forever in idleness with no more purpose than to make the molecules dance about? Think what a wonderful thing it would be if we could only get all that energy back into service. At present, when we run a train from Philadelphia to Chicago, we burn up about sixty tons of coal. When the train has arrived at Chicago, it has sensibly the same potential energy as it had in Philadelphia, since Chicago is at approximately the same altitude as Philadelphia. Even though the train has scaled a mountain on the way, it has descended again by the time it has arrived at Chicago. It had no kinetic energy just before it started, and it has none when it is brought to rest in Chicago. What has become of all the energy provided by burning the sixty tons of coal. In the first instance, some of it went to boil the water in the boilers. The steam pressure made the engine run, and some of the energy went into that process. A large portion of it went simply to heat the condenser of the steam engine. But even the part that went to run the engine finally

became converted into heat in the friction associated with running the train, in the operation of the brakes, and so forth. In fact, practically all of the energy supplied by the sixty tons of coal finally went into that particular form of energy which is called heat—into molecular motion and the like. If only we could collect it in some way and make it function again, we could run the train back to Philadelphia without using any more coal. In fact, if we could do this kind of thing, we could make our trains and much of our machinery run forever with but one initial supply of energy. There would be no violation of the principle of the conservation of energy. No energy has evaporated into nothingness as a result of the train's going to Chicago. If this kind of thing could happen, most of our transportational and mechanical operations would involve nothing more than the continual transference of energy from one form to another and back again with the accompanying happy state of affairs for our-selves that we got where we wanted to go and did what we wanted to do without payment of anything. Now, our experience gives us the suspicion that we cannot do this kind of thing, and that something is wrong with any assumption to the effect that we can. But what is wrong? The pro-cedure does not violate the conservation of energy. It does not "cost anything" in the long run, in the form of disap-pearance of energy, to do this kind of thing. If I should inquire of Nature as to why I cannot do this thing which I should so much like to do, Nature would probably answer me thus: "My laws are more restrictive than the conservation of energy. They require that conservation of energy shall be obeyed, but they also require other things. Just because you keep your energy bank book balanced that does not give you the power to do anything else you please."

"But how," I demand of Nature, "am I to know what things of this kind are impossible?"

And Nature says, "If you could see all the detailed actions which are taking place in my realm, you would see for yourself which things are forbidden. There would, in fact, be no need

for forbidding. These things could just not happen. To attempt to see the matter in this way would be too complicated. If I were to attempt to tell you all of the individual things which would fail if you tried them, the tale would be too long, and you would not see much connection between the parts. However, I find that by making one decree, I can settle the matter for you. There is just one thing which I tell you you can never do. I know that I need say no more, for I know that, without violating that decree, you would never be able to do any of the thousand-and-one things you want to do, and I don't want you to do."

That one decree is the Second Law of Thermodynamics. It places a restriction upon the ways in which work can be obtained from heat. It looks as though the second law of thermodynamics was invented in the Garden of Eden, when the Deity said to Adam, "In the sweat of thy face shalt thou eat bread." The example which I have already given—the impossible process of collecting all the heat generated by friction, etc., and converting it back to work—is a rather complicated illustration of a process which could be seen to be impossible by means of the second law of thermodynamics, and I only cited it on account of the spectacularness of its nature. It is not easy to state, in non-technical terms, just what the second law of thermodynamics is, but I shall try to illustrate the essentials.

In the first place, it is necessary for us to heed the schoolmaster's warning to all beginners in physics concerning the necessity of a careful distinction between temperature and heat. Speaking crudely, temperature is a measure of the degree of hotness of a substance. Now a cup of boiling water and a barrel of boiling water are equally hot; but, it obviously took more heat to raise the barrel of water to the boiling point than was necessary for the cup. I think I need say no more than that to recall to you the distinction between temperature and heat. Physically, this heat is nothing more than the energy of the ultimate individual entities of matter's

structure, such as the molecules of the heated body, and our problem concerns how we are to be able to get it out of the heated body and make it do something. If we say we can never make this molecular kinetic energy do any useful work we are wrong, because a steam engine works by making use of the molecular energy of the hot steam. But if we say we can always use molecular energy for useful purposes, we are wrong; for, if we could, there should be nothing to prevent us from draining all of the molecular energy out of the earth by cooling it to absolute zero, and then using it to run all of our machinery. It would finally go back to the earth again in the form of molecular energy when, as a result of the friction in the machines, it had become degraded back to the molecular form. Then when it had gone back into the earth we could proceed to use it again. The earth would be as good as the widow's cruse of oil of biblical fame.

Now when we come to ferret out just how and how not, when and when not, we are able to utilize molecular energy, we find that the whole question boils down to this: We can get the molecular energy out of matter in a practically useable way [1] only provided that we utilize at least two pieces of matter, one colder than the other. Then we must take heat, *i.e.* molecular energy, from the hotter body, but we must not use all of it; we must pay a tax to the body of lower temperature. The laws of nature make the inanimate world like a conglomeration of philanthropists of varying degrees of wealth (symbolized by the temperature in the case of the inanimate things), and characterized by the fact that you can get a donation from one of these philanthropists for a desired purpose, provided only that you promise to give some of the donation to one of the poorer philanthropists. If you try to get money from the philanthropists in any other way, Nature conspires to block your operations so that you

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[1] I use here the designation "practically useable way" as a symbol of processes in which, in the operations incidental to the utilization of the energy, the machine involved repeats continually a cyclical process.

can only do it once.[1] Every transaction is thus accompanied
by a kind of sales tax; and this tax is terribly high.   In the
case of an ordinary steam engine. it amounts to more than
seventy per cent of the energy transaction involved.   In the
inanimate world, Nature seems to like to utilize every activity
for the purpose of helping the poor (symbolized by low tem-
perature bodies) at the expense of the rich.

Speaking crudely, we may say that Nature likes to
equalize temperatures.   Everybody knows that Nature likes
to equalize the temperatures when two bodies of different
temperature are placed in contact.   We should be very sur-
prised if, under such conditions. the hot body became hotter
and the cold one colder.   But the spirit of the second law of
thermodynamics is to the effect that, even in the more subtle
processes where heat is transferred between bodies through
the medium of work. Nature likes to equalize temperatures
as a result.   Nature is like human beings.   Human beings
will permit sections of society to exist in different states of
prosperity, but whenever she gets a chance in the form of a
revolution. things so arrange themselves that the revolution
reduces the disparity.[2]   And so. Nature will allow things to
exist at different temperatures. provided that we take pre-
cautions to guard them from loss of heat by such processes
as conduction; but, if we give Nature a chance by starting
anything. she will take advantage of it for the purpose of
making the temperatures of the various things more nearly
equal than they were before.   The second law of thermo-
dynamics, which symbolizes the foregoing principle, is thus
the most politically radical doctrine in the universe.

The second law of thermodynamics expresses itself by
denying the possibility of processes which do not conform to
a certain criterion.   It tells us what we cannot do.   Our

[1] I am here citing an analogue to the case where, for example, in a system all at
one temperature initially, one could obtain work by allowing a gas to expand and so
cool, but could not get the system back to its original state with a net accomplishment
of work as a result, without utilizing the principle of transference of some heat from
a warm body to a colder one.

[2] However, this analogy must not be pressed too far; for human beings seem to
possess the power to recreate the disparity again.

laurels earned by obedience to it are like the laurels of the saints, who appear to have been canonized for the most part for what they avoided doing. But it so happens that a sufficiently comprehensive statement of what cannot be done sometimes implies a statement of what can be done. If we knew the complete mechanism of the universe in all its parts, the second law of thermodynamics would not, of course, add any information; but, when we do not know all about the processes, the second law can tell us something. Thus we know that water expands when it freezes; and, knowing this, we can deduce from the second law of thermodynamics that the melting temperature of ice must be lowered by subjecting the ice to a pressure. This result is, of course, well known as an experimental fact. When we squeeze a piece of ice, it melts, because its temperature, which was low enough to keep it frozen before the pressure was applied, is no longer low enough after the application of the pressure. However, apart from our experimental knowledge of the fact itself, it is by no means an *obvious* thing that the melting temperature of ice should be lowered by pressure. The opposite is true for wax. Without delving into the realms of atomic structure, we know far too little to see "just why" the melting point of the ice is lowered. The second law of thermodynamics relieves us of the necessity of knowing all about the process. It tells us the answer without our going through the complication of seeing "just why." It may appear a very trivial piece of information that the second law has given us in this case. Yet, if the melting temperature of ice had beeen raised by pressure; or, even if it had been lowered, but by an amount different from that predicted by the requirements of the second law of thermodynamics, I could take all the heat out of everything around and make myself a millionaire. It would then be possible, in principle at any rate, to construct a machine which would continually perform work by simply cooling everything that there was to cool. We could drink the heat out of our poor old earth, out of the sea, and everywhere, and could go on running our trains and

street cars with the energy thus made available. Just as
now we use the earth's coal, so, under these conditions, we
could use its heat. I do not refer to the use we could make
of its internal heat, owing to the fact that the inside is hotter
than the outside. We could use that part quite in harmony
with the second law of thermodynamics, the only difficulty
being in getting at it. I refer to the heat which, under the
postulated conditions, we could obtain from the earth even
though all of it were at the temperature of its exterior. We
could obtain a good deal of power in this way. We could
obtain about ten thousand million horse power for ten
thousand million years. Moreover, when we had used the
heat once, and it had gone back to the earth, we could use
it again. But, while the second law does not tell us the details
of all Nature's workings, she tells us that we cannot do any
such thing as this. Only by equalizing the temperature
differences around us can we devise practical schemes for
converting heat to work. As long as we have bodies at
different temperatures, we can convert heat to work. If we
have only a few hot bodies, we shall soon exhaust our pos-
sibilities in this respect, because the hot bodies will become
cooled and the cold bodies warmed by the operation of the
very processes we use for converting the heat into work; and,
when all differences of temperature have been wiped out,
our possibilities come to an end.

The second law of thermodynamics rests upon the fact
that all the consequences which it has predicted have been
found to be true experimentally. It is like a race-horse
tipster. It lives on the truth of its former predictions. It
will only continue to live so long as its predictions continue
to be in harmony with the facts; but it has made such a lot
of true predictions in the past that we have become accus-
tomed to trust whatever it predicts when it predicts new
consequences.

When one has formulated the law of gravitation for the
motion of the heavenly bodies, it is possible to see in terms of
it just why the planets behave as they do; and, during the last

century, a good deal of thought was expended in an effort to see just why the second law of thermodynamics should hold —to see just what detailed story of the atomic forces of Nature could be responsible for this tendency of matter to seek always to equalize temperatures, not merely by the processes of conduction of heat from the hot to the cold, but by other processes as well. The mathematician got busy and showed that this tendency to equalize temperatures was the same story, but in other words, as one which would say that Nature is trying to progress in such a way as continuously to make a certain quantity greater. That quantity was called the Entropy. It was possible for the mathematician to calculate quite definitely in terms of such things as the pressure, temperature, and so forth, of any particular part of the universe, what the value of that mysterious quantity, the entropy, was, which had such a desire to become as great as possible. The quantity itself was not a very familiar looking thing in terms of our ordinary concepts. It was not like mass or velocity, or any one of the things we meditate upon in our every-day thinking. It was a sort of combination of these familiar things. But after all, we have no reason to be alarmed at that. For, if you should make, in precise terms, a definition of a golfer's handicap, it would seem a rather complicated and abstruse thing to one who was not a golfer. Nevertheless, it is a very useful thing in golf. It is the thing which has useful properties in telling part of the story of the activities of the golfer; and so this entropy was the thing which had the useful properties in the science of thermodynamics. Nevertheless, having admitted this new concept into the subject, the mathematicians and physicists still continued to try to see by an appeal to the more detailed mechanisms of atomic processes, just why this quantity should have such an ambition to grow and grow in the universe. And the more the mathematicians thought about the matter, the more perplexing the problem became; for, without pinning oneself too closely to any particular form of atom theory or fundamental laws, it seemed that almost any

of them would have no more desire to persuade the entropy
to increase than to decrease. A simple illustration of the
processes in this connection may be obtained by considering
the case of the solar system; and it will be a little better if we
complicate our ideas a little by laying a little more stress upon
the features concerned with the mutual pertubations of the
planets than is done, so that we picture a situation in which
the orbits of the planets do not repeat themselves with
perfect regularity, but on account of their mutual perturba-
tions, go on changing a little from year to year. As a matter
of fact, we do not have to apologize for this extension of
ideas. It is really no extension at all. It is actually hap-
pening, only to a very small degree. The smallness need not
worry us, we have plenty of time to watch it, and let us go on
watching it. Suppose now at some instant we should sud-
denly reverse the velocity of every individual body, planet,
satellite, comet. Then, the laws of gravitation tell us a
remarkable thing. They tell us that the whole history of
the solar system will re-describe itself backwards, and in
every detail. In fact, as far as the laws of astronomy are
concerned there is no more reason why the system should go
through a sequence of changes in one direction in time than
that it should go through exactly the same sequence in the
reverse direction. The feature which is responsible for this
state of affairs is, moreover, not particularly characteristic
of the law of gravitation, but is characteristic of almost any
set of laws of the kind we had been accustomed to think of in
physics, no matter how complex the laws might be. Thus
if, with laws of this type, we should vision a set of molecules
composing various pieces of matter which were originally at
different temperatures and have shared their heat so as to
be now at the same temperature, and if then we should
suddenly reverse the velocities of all the molecules; or, more
precisely, every part of the molecules which has motion, it
would seem as though everything, every state and event,
should take place backwards in time, so that the bodies
would proceed to acquire a difference in temperature. The

kettle which was put on the fire to get hot at the expense of the fire becoming cooled, would, under these conditions, become cooled once more and heat up the fire.

An equally remarkable situation is encountered by considering the well-known case of a box divided into two halves by a partition. The right-hand side is evacuated and the left-hand side is filled with air. I now punch a small hole in the partition and the gas rushes through the hole until both halves are equally filled, and then the process stops. You are content—I am surprised. One of the differences between the physicist and the layman is that the layman is apt to be confused and surprised when the physicist is happy and contented with a situation, while the physicist is surprised and worried when the layman sees no earthly reason why he should be worried at all. And so I invoke my professional prerogative of being surprised that the gas always shows a tendency to equalize itself, and never shows a tendency which would result in the equalized gas getting restless to the extent of causing all the molecules on one side to leave that side and go into the other side, like rats leaving a ship. Of course, I have no right to be surprised that there is no demon who takes it into his head to reverse the motions of all the molecules now and again. What surprises me is that none of these reverse processes seem to exist spontaneously in Nature, since the ordinary physical laws we have been accustomed to think of, even with a wide range of possible extensions in their form, have no preference against these reverse processes. And so the physicist has been compelled to admit to himself that, within all reason, these reverse processes can occur, and do occur; and yet he has to see a way in which they do not result as a practical fact in what would appear to be absurd results in the light of our experience. The key to the dilemma seemed to reside in the principles exemplified in the example which I showed earlier concerning the red and colorless beads. I started with the colorless beads on the top and the red beads below. On shaking them, I have gotten them into their present state of more or less equal distribution. If I

shake them again, I shall be surprised if they do not look very
much as they are now. Yet, every time I shake them I
redistribute them, and give them one of the many oppor-
tunities which exist for their taking another distribution.
Among those many opportunities is that one which takes
them back to the state where the colorless beads were on top
and the red ones below, but I shall be very surprised if they
find that pattern. Every time I shake them, I change them,
but, of all the opportunities which exist for them on such a
change, so many take them to another state in which they
are mixed up in a manner which, as regards its essential char-
acteristics, is the same as that in which they now are, that
the chance of their getting out of this state is infinitesimal.
The beads are something like a man in a maze. He tries
once to get out and fails. He tries again and fails. There
are so many ways in which he can try and yet stay more or
less where he is, and only one way in which he can get out,
that he may remain in the maze a long time. Yet, there is
no difficulty in getting into the maze. He does that on the
first try, just as I mixed up the beads from a state of order to
one of chaos without any difficulty at all.

And so, our difficulty in the matter of bodies which are
at the same temperature not starting to diverge in tem-
perature, is not to be solved by denying the possibility that
they can do so, but by emphasizing the fact that when they
make any change, the path they take is so enormously more
likely to bring them to another state in which their tempera-
tures are still the same than it is likely to bring them to any
other state, that the chances of the realization of such other
states is infinitesimal. It may be of interest to cite once
more the case of the box with the partition, and to emphasize
that the reason that the molecules distribute themselves
throughout the two halves equally, rather than in one half
of the box only, is bound up with the relative chances of
occurrence of the two states. I must not attempt here to
define my terms too precisely, since to do so would require
a long digression for that purpose. It will be sufficient

for the spirit of the matter to quote a statement cited by Sir Arthur Eddington which I shall paraphrase slightly, to the following effect: "Suppose that a number of monkeys are provided with typewriters and are allowed to play upon the keys as suits their fancy, turning out pages and pages until they have finally typed as many letters as there are letters in all the books in the British Museum. Let us then bind these writings of the monkeys into volumes. The chance that the letters will fall in the necessary order actually to reproduce word for word all the books in the British Museum is enormously greater than the chance that in the room in which you are sitting, for example, all of the molecules will be found at some instant in one half of the room. The same principles would apply in lesser degree to a number of people seated in a large auditorium. The number of ways in which we can redistribute them on the chairs is much larger if they occupy the whole auditorium, than if they crowd themselves into half of it. Yet, I surmise that if there is a conjurer on the platform, they will all be found in the front half if they can get in. May there not be something like this in Nature. When I spoke of there being many more paths from order to chaos than from chaos to order, I only intended to imply that such *might* be the case. It must certainly have been so in the case of the beads. What is certain is that there are enormously more states of chaos that there are states of order. There are enormously more ways in which the red and colorless beads can be arranged and re-arranged and still stay mixed than there are ways in which they can be arranged and re-arranged with all the colorless ones at the top and the red ones at the bottom; but the number of ways in which a system can be re-arranged so as to remain sensibly the same as it was before is not necessarily indicative of the number of opportunities for it to make the re-arrangements. If you should distribute all the dollar bills equally among the people in this country, the number of ways in which by interchange of dollar bills you could keep the distribution of wealth undisturbed is enormously great compared with the number of

ways in which the dollar bills could be re-distributed among different people so as to retain the relative distribution of wealth which we now have, in spite of the fact that we do not in our different distributions limit ourselves to the cases where the *same* people are always wealthy. Yet it does not result as a consequence that we find equal distribution of wealth. The reason is that the laws which govern the flow of wealth tend to favor the accumulation of wealth un-equally. Indeed, the fact that if we started with an equal distribution of wealth we should soon realize an unequal distribution is very closely analogous to a situation which we would have if bodies originally at a uniform temperature made distribution of their heat in such a way that some of the bodies became very hot at the expense of others being very cold.[1]

And so it was necessary for the physicist to commune with himself as to whether he could gather from the laws of Nature, as he knew them, enough to tell him that the prob-ability of the existence of a state as measured by the number of ways in which it could be realized was really a measure of the chance that the system would get into that state. It is rather difficult to say in reasonably non-technical terms just how the physicist set about this, but I will do my best. Suppose, as an analogy, I imagine our solar system changed about. It is possible, in imagination, to take the elements which composed it, the comets and the planets, and set them off in other orbits, with the earth in the orbit of Halley's comet, for example, or in some possible orbit which does not happen to be occupied by any known comet; and to make corresponding modifications in the roles of all the other bodies. I can have the moon going around the sun on its own account in a more independent manner than as the servant of the

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[1] For the interest of those who are specialists in the subject, I would emphasize that we must not place too much weight upon a supposed difference between the human and the physical problem founded upon the different capabilities of the indi-viduals who acquire different amounts of wealth; for, if we wish, we can invoke the different kinds of coordinates of the physical system as symbolic of different kinds of individuals. Then as to whether or not one class will be favored will depend upon the laws of the subject.

earth.   It is to be supposed, however, that in this new ar-
rangement of the heavenly bodies, I adjust matters so that
the total energy is the same as before.   The new solar system
which we produce may be called a new possible state of the
entities contained in the old one.   I may perform this trans-
formation again, and again, and in fact a very large number
of times, and then contemplate this spectacle of millions of
solar systems all the same as ours in the sense that they con-
tain the same entities, but all in different states.   I shall
suppose that in this galaxy of states which I picture, I include
a representation of every possible state which the elements
of our solar system could exist in, subject only to all the
states having the same energy.   And now, if I am interested
in discussing the kind of way in which the solar system
changes spontaneously with time when in any one of its
states, I have the whole picture before me, in the sense that
there is a representative of every state which can exist.   Like
Joshua, I have commanded time to stand still so that I may
look at the solar system for an instant; but I have improved
on Joshua, for I have demanded that at one and the same
time I may have a look at the solar system in each of the
configurations which in its whole history it can occupy.
Having had this vision, let time start moving on once more.
Each of our pictures of the solar system will proceed to change.
The way in which each changes will be determined by the
laws of Nature as applied to the particular state from which
the change is to progress.   Some of our pictures may rep-
resent very stable states, in the sense that the laws of
Nature are content to leave them very much as they are.
Others may suffer rapid and drastic changes directly the
laws of Nature operate on them.   In my original mapping
out of these various states I gave a sort of impartial picture of
all possible states.   Of course I could not draw an infinite
number of pictures, but I drew in my mind's eye one state,
then another which was a little different from that, then
another a little different from the second, and so on, so that
there was no particular state of the universe that anyone

could bring me such that I could not find something like it in my chart.   I am like a criminologist who has drawn a lot of pictures of finger-prints differing successively from one another, and so complete that there is no criminal whom you can bring me for whom, on finger-printing him, I cannot find one of the previously drawn records which is something like the actual finger-print obtained.   And so, when I drew all my pictures of the solar system, I gave a fair representation to all possible states of it.   But the laws of Nature may not like my drawings.   Nature may say, "Truly that picture number one thousand and three, which you have drawn, is a possible state of the solar system, but the solar system could never exist for any length of time in a state anything like it. I should drive it out of that state as fast as I could, and into one more pleasing to me."

"Well," I say to Nature, "take these pictures which I have drawn as starting points, develop each of them as you will, and let me have another look later."

Then it may be that, as time progresses, Nature will change certain of the pictures very little, while taking others. which she likes less, she may gradually modify them in such a manner that, when she has gotten things as she wants them, these states will be represented very poorly, all of the original representatives of them having been guided out of them into states which Nature likes better, and with no compensation in the form of a return from other quarters.   If now I have another look at my modified pictures, I may feel aggrieved. I say to Nature, "You have made a nice mess of my work of art.   What have you done with ninety-nine per cent of my nice pictures of the solar system?   Why have you left only these few?"

"I didn't like the others," says Nature, "they were terrible, so I changed them."

"But," I say to Nature, "this is very unfortunate, for I want to tell you something.   In nearly all of those pictures which you have destroyed, there was one central idea, an idea common to all.   This idea does not exist in the very

specialized pictures which you have left me.   As a matter of fact, such an overwhelming proportion of my former pictures had in them that central idea, that property, that I have told everybody that the idea was a fundamental consequence of the workings of your laws, in the sense that whatever state the solar system may be in, that property will almost certainly be found in it." [1]

"Well," says Nature, "perhaps it was because I didn't like the property that I ruled it out.   What kind of a property was it anyway?"

"A very peacable property," I reply, "one which does not disturb anything or produce any crises in the universe."

"Ah! a back-boneless property," says Nature, "a fine property to work for in nature, a fine property to make a universe out of.   No wonder I didn't like it."

Now let us point out the significance of our analogy. Just as I asked you to vision all possible states of the solar system in one picture, so the mathematical physicist has visioned in one picture all states of an assemblage of molecules and of distribution of energy among them.   All but an insignificant proportion of the states were ones in which the molecules had gotten down to a sort of share-equally-for-all basis, of the kind I have symbolized earlier in this address, a condition in which the average energy of a group of oxygen molecules was the same as the average energy of a group of hydrogen molecules; a condition, moreover, in which things other than molecules had come to eat out of the trough. Each individual wave length of the spectrum of the heat waves of the radiant heat passing back and forth in an enclosure claimed an equal share of the energy.   There are an infinite number of different wave lengths, so that if the distribution of energy were made in this way among the molecules and among the waves there would be only an infinitesimal amount for each of the claimants.   All but an infinitesimal proportion of the states of the molecules and

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[1] I need hardly remind the physicist that the property here spoken of is to be taken as the analogue of one of the properties (such as equipartition of energy) of the so-called normal state.

waves associated with them possessed this lugubrious prop-
erty. So the mathematical physicists appealed to the laws
of Nature to see whether they would not do something such
as, for purposes of description, I have visioned them as doing
in the hypothetical case of the pictures of the solar system.
Would not the laws of Nature exercise a sort of presidential
veto against the overwhelming majority of representatives
of the universe which were voting for chaos, and for the least
amount of differentiation between the individuals, the least
specialization in properties? Now, the truth was that the
physicist did not know what the laws of Nature really are,
but he was able to show that, provided only that they were of
what is known as a dynamical type, they would render no
assistance, but rather would just let the universe run to the
dogs.[1] I fear I cannot pause to explain just what is meant
by a dynamical system. The physicists will know, and, I
fear, the others would get but little enlightenment if I told
them. It will suffice to say that the dynamical type of law
is one which, while it permits a wide modification in detail,
possesses certain characteristics much beloved of classical
physicists. Provided then that the laws of Nature were of
this dynamical type, the changes which the laws permitted
would allow the universe to wander indiscriminately through
all the possible pictures which we could draw of it,[2] so that
the chance of the universe finding itself in one of those barren
states to which I referred would be, on this basis, over-
whelmingly large.[3] As the physicists meditated upon this

[1] I refer here, of course, to the implications of the famous theorem of Liouville,
which is founded upon laws of the Hamiltonian type.

[2] A few reservations must here be made for the benefit of the technical reader.
The argument given excludes the case of re-entrant paths, such as are associated with
dynamically degenerate systems. The general implication seems to be to the effect
that a sufficiently fine-grained consideration of the system would show that, in the
last analysis, there were no absolutely re-entrant paths and that, given time enough,
the system would occupy all states consistent with the conservation of energy.

[3] Even should we accept the implications here suggested, nevertheless, as I re-
marked twenty years ago in a discussion of this matter in the London and Dublin
Philosophical Magazine, there is no reason for wonderment at our present condition.
We may admit the extreme improbability of the existence of the universe in its present
state, but we must remember that it is only during the very rare periods of existence
of this improbable universe that there will be found in it those highly improbable
beings like ourselves to study it.

state of affairs in relation to the story of the older framing
of the laws of thermodynamics, it turned out that that
tendency of the apparently mysterious quantity, entropy,
to become greater and greater, which tendency was the
symbol of what the second law had to say,—that tendency
could be nothing more than an expression of the tendency of
systems to seek states of greater and greater probability.   In
fact, the mathematicians were able to show how, by assuming
that the entropy was nothing more than an expression of the
probability, a very elegant story of the meaning of the science
of thermodynamics could be built up.   Entropy, as it had
existed in the mind formerly, was simply a quantity which
the physicist had accidentally stumbled upon and found how
to measure because it had an important property.   It now
appeared that the physicist, when measuring entropy, was
really measuring probability in spite of the fact that what he
actually measured did not look like probability.   The phys-
icist was like a little boy looking at the log attached to the
stern of a ship.   What he sees is a pointer going round and
round.   What that pointer really measures is the speed of
the ship.

Now the physicist likes to generalize.   The idea which
presented itself in examining the ways of molecules and atoms
and heat radiation gave rise to the thought that all energy,
even the energy of the internal structure of the atoms, and
of the very electrons themselves might be seeking to free
itself from the bonds of structure and join the ranks of chaos
where little pieces of it would have so much greater freedom
to jog about from one thing to another without doing any-
thing in particular.   If we accept this idea as a principle—
a starting point in itself—then there is of course nothing
further to be said.   From the practical standpoint the ques-
tion at issue is "How far are we *compelled* to accept the idea?"

Now the failure of the laws of Nature to coöperate in
preventing the universe from going to the dogs is exactly in
line with the requirements of the second law of thermody-
namics over that region of experimentation which has given

rise to the law. It must be regarded as an experimental
fact that Nature seeks to go to the dogs in some of her activi-
ties; and, any reversing principles which we contemplate
introducing into the laws of Nature must not deny the
privilege of Nature to go to the dogs when she wants to.
How far can we go without running contrary to the demands
of experiment and experience?

It is true that, in the sense in which the mathematician
counts different states of a system, there is an overwhelm-
ingly infinite number of states which are representative of
the state of dead chaos which I have pictured earlier; but
this, of itself, does not necessarily mean that there is an
overwhelmingly large practical chance of the universe seeking
an ultimate permanent existence in these states. We must
not assume that some sort of infinitely improbable and com-
plicated law of Nature would be necessary to guide the
universe out of chaos. Because there is so much water in the
sea wherein I can drown, that does not necessitate an in-
finitely complicated ship to take me across the ocean. It is
true that the law structure of the old classical dynamics
provided no succor in the matter, but as every physicist now
agrees, that law structure does not hold for atomic processes.

It is readily possible to invent a law structure which will
avoid the unpleasantness of ultimate dead chaos. This is
not the time to demonstrate the fact; but that there is nothing
mysterious in it may be seen by citing again the analogy
which I have already cited, concerned with the distribution
of dollar bills among the world's populace. Apart from the
laws governing the flow of business and of dollar bills, practi-
cally the same mathematical principles are available to show
that the state of equal distribution of these bills among all
the people is overwhelmingly the most probable distribution
in the ultimate state, as are available to show that, in the case
of the physical world, an ultimate state of chaos, of a universe
run down, is overwhelmingly probable. As I have implied,
the enormous odds in favor of equal distribution of the dollar
bills have practical significance only in the absence of con-

trolling laws; and it is not hard to understand that the laws of economics and of man's behavior may be such as to prevent such a distribution of wealth.

If I should cite a still simpler example, but one in which the laws concerned are those governing animals, I would say that, if I should bring several million flies into this room, I could prove that the distribution of the flies which, by mathematical calculation, was the most probable distribution would be one in which each cubic foot of space contained practically the same number of flies. Yet, you all know what would happen if I put a bowl of honey on the table. I know that some of my physicist friends will point out that the classical theory has a way of taking account of things like the honey, and that the potential energy, in its control of the unequal distribution of molecular atmospheric density with altitude, for example, provides an illustration. To this I agree, but hasten to point out that this latter fact itself is just an illustration of how the coöperation of law structure with the numerical operation of counting states does produce an ultimate result in which the law structure can show its mark.

I feel, therefore, that, in our present rather incomplete knowledge of the laws of atomic processes, we cannot say that the laws demand chaos as the ultimate fate of the universe. On the other hand, there is nothing in our present knowledge of those laws to deny such a possibility. In the light of this state of affairs, it is encumbent upon us to look around in the universe and learn what we can as to the way in which things seem to be going on as an actual fact. We find that the sun and stars are very hot. We have evidence that they have been hot for so long that had there been no sources available for the supply of heat, they must have cooled ages ago. All of the more obvious sources of supply of heat which had been examined by the physicists, gravitational potential energy, radioactive energy, and so forth, had proved hopelessly inadequate; and it became necessary to draw upon atomic energy; and to go even further and draw even upon

the energy associated with the very existence of such things as protons and electrons.

Modern physics has come to recognize a very close relationship between mass and energy, in the sense that if mass, in the sense that a particle has mass, is caused to disappear, then energy appears in proportional amount in the radiant form. If a number of protons and electrons are brought together, it is known that they lose mass; and it is believed that the disappearance of mass would be associated with the radiation of a proportional amount of energy. This relation between mass and energy, first sensed from the principle of relativity, has been verified in certain instances experimentally. The amount of energy which is the equivalent of the mass of even a drop of water is surprisingly large, so large, in fact, that the complete annihilation of the drop would result in enough energy to supply two hundred horsepower for a year. The conditions of very high temperature and pressure in the interior of the stars are believed to be favorable to this transformation of mass into radiant energy, and it is believed that in this source, by the devouring of its own substance, does the star refill its coffers of energy to pay forth continually to space that tax demanded by Nature. While we do not have a complete picture of the passage of mass into energy in the sense that the materialistically minded would demand a picture, we are driven to believe that it occurs. No other source of energy seems adequate to explain the heat known to be continually radiated from the stars. Here then we see going on, as it were, the process of continual degradation of energy and of matter itself to the form of ultimate chaos in the form of radiant heat energy. The logical end of this story would be the complete conversion of all matter into heat energy. It is true that the evidence of our experience teaches us that the devouring process would go on much more slowly when the stars were old; but eternity is long, and there is plenty of time. Is there any way back from radiant energy to matter? As a matter of fact, there is, and the method has been admitted by all physicists who are less than

thirty-five years old, and by most of those who are older, as a perfectly respectable member of the society of physical methods, although the manner of its occurrence is at present exceptional. I must remind you that radiant energy exists in the form of definite units characterized in magnitude by the frequency of the radiation concerned. These units are called photons. Now the idea is that on certain rare occasions, a photon comes into such violent collision with the nucleus of an atom as to result in a kind of catastrophe. In this catastrophe nothing in particular happens to the atomic nucleus, but the photon becomes mathematically irritated in such a manner as to cause it to decide to change its existence, commit suicide, and become resurrected as a pair of charged particles. If you should ask for a crude analogy, I suggest that you think of a spiritualistic seance. The photon is the ghost, the pair of charged particles constitutes the materialized ghost, and the atom is the medium. Now our ideas associated with the subject tell us that if our atom is at rest, this kind of phenomenon could not occur unless the photon had an energy enormously greater than that possessed by the kind of photons associated for the most part with heat. However, if the atom moves toward the photon with great energy so that it moves with a velocity comparable with that of light, and if we stand on the atom, the photon will appear like a photon of shorter wave length. This follows, in part, from the same principle as that which causes the pitch of a whistle to sound higher if you rush towards it, or more exactly from the theory of relativity. Thus to the moving atom, the low-energy photon will look like a high-energy photon; and the theory of relativity tells us that this fact will irritate the photon just as much as if it had been a high-energy photon and the atom had been at rest. The photon will change to a pair of particles and rob the atom of some of its energy to accommodate it in its new state of life. Were it not for the fact that we have to borrow the assistance of the high-energy atom, which high energy atoms are hard to secure in any large number in Nature, this process

would constitute a very suggestive one for the reconversion of radiant heat energy into matter. As matters stand, we have no suggestion from the laws of atomic physics as to the processes by which photons could become irritated without the presence of the atom. They do not possess the power to become irritated simply by their boresome existence; and, even if they did, a low-energy photon, without the assistance of an energy-lender in the shape of a fast moving atom, would not of itself have enough energy to enable it to change into a pair of particles. If we could see ways in which many photons could coöperate to produce particles, the path back to matter would be easier.

It is perhaps not without interest to contemplate a final state of the universe in which there were practically nothing but photons wandering throughout space. and compare it with what is taken by some as the starting point of our universe, a condition in which all the atoms of matter are distributed throughout a space of finite extent in the sense of the theory of relativity. It has been suggested that under such conditions the moving atoms will come together in clusters under the influence of their motion and of their gravitational attraction, to form nebulæ, which again under similar influences form clusters which condense to form the stars. From this simple beginning, there grows, through the action of gravitation, in feeding its energy into the motion of the atoms, a state in which the stars form and increase in temperature, producing in turn all of those extraordinary phenomena such as transmutation of matter into energy, radiation of heat, and so forth, which we have only barely touched upon in this address. The question is whether, starting with a universe of photons, a similar, or rather an analogous, state of affairs can result. It would presumably be necessary to provide for laws and forces by which the photons could gravitate together, and produce conditions favorable to their conversion into matter; but, just as the effects of gravitation while present on a large scale are almost immeasurably small in the case of bodies of small size, so these forces,

potent perhaps to form the basis of the recreation of the
atoms, may be such as to prevent there arising conditions in
which, in our ordinary experiments, a violation of the second
law of thermodynamics would be found.   In invoking such
processes as those I have hinted at, perhaps a good test one
might set himself as a test of the reasonableness of the idea
is to inquire whether the process, violating as it does the
spirit of the second law of thermodynamics, would, if it
existed, have prevented people from going through exactly
the mental processes they have gone through leading to the
very discovery of that law, and to their subsequent belief in
its generalized validity.

In conclusion, I would add that I hold no brief for trying
to save the universe from its ultimate fate.   My object has
been simply to discuss the question as to whether or not that
fate is inevitable in the light of our existing knowledge.   The
avoidance of that fate may involve some additions to our stock
in trade of physical concepts.   Among other things it may
involve the coöperation of several photons in single acts, in
the sense I have hinted, so that, to paraphrase the statement
concerning the value of the work of him who can make two
blades of grass grow where but one grew before, we may say
that perhaps he who finds a way to make many photons act
where but one would act before may have found a way to
rebuild the universe.

THE COMPOSITION OF COSMIC RAYS

ARTHUR H. COMPTON

(Read April 20, 1935)

As a starting point for study of cosmic rays, adequate knowledge of their nature has long been recognised as perhaps our most fundamental problem. At first, by analogy with gamma rays, their extreme penetrating power was taken to mean that the cosmic rays are photons, *i.e.*, electrically neutral particles like light but of enormously greater energy. In 1929, however, some experiments by Bothe and Kolhörster, using coincidence counting tubes, gave a strong indication that the primary cosmic rays are electrically charged particles. They at once called attention to the fact that such particles should on approaching the earth be deflected by the earth's magnetic field so as to reach the poles more easily than the equator. This suggestion led to a series of extensive investigations which have now given us what seems to be adequate evidence that the primary cosmic rays are in fact electrical particles. I want to review this evidence briefly, and then explain how further experiments have enabled us to analyse these electrical rays into three components, each of which seems to be identifiable with one of the elementary constituents of matter.

PRIMARY COSMIC RAYS ELECTRICAL

In 1929 J. Clay had just published his first measurements indicating a greater cosmic ray intensity in Holland than in Java. This difference Bothe and Kolhörster ascribed to the anticipated action of the earth's magnetic field. At first, expeditions by Bothe and Kolhörster, Millikan and Cameron, Kerr Grant and others failed to confirm Clay's repeated findings. Then came, however, several extensive series of observations which have established the existence of his

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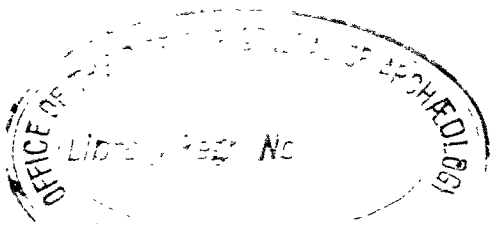
latitude effect, and have thrown a flood of new light on the composition of cosmic rays.

Theoretical studies by Störmer, Epstein, Rossi, Lemaitre and Vallarta, and others showed that if electrical particles approach the earth from remote space, there is roughly speaking a critical latitude for rays of a given energy such that nearer the equator the rays cannot reach the earth and nearer the poles they strike the earth freely. The earth's atmosphere does not permit particles with energy less than about 2.3×10^9 electron volts (protons) to reach sea-level, and for this energy the critical latitude is about 50 degrees. Thus at higher latitudes than 50 degrees all particles capable of penetrating the atmosphere will pass freely through the earth's magnetic field, and no change of intensity with latitude should occur. At lower latitudes, however, more and more of the rays should be removed by the magnetic field, resulting in a minimum of intensity at the equator. At higher altitudes, where lower energy particles are transmitted, the latitude effect should extend to correspondingly higher latitudes.

The recent cosmic ray surveys have given results in complete accord with these calculations. During 1931 to 1934 we had twelve different expeditions including some eighty coöperating physicists, making measurements at more than a hundred stations widely distributed over the earth. The data showed that at magnetic latitudes higher than 50 degrees no significant variation with latitude occurs at sea-level. From the equator to 50 degrees, however, there is at sea level an increase of intensity of about 16 per cent. Similar contemperaneous measurements by many different observers have led to essentially the same results. In Fig. 1 is shown a typical set of our data, giving the intensity of the cosmic rays at sea-level as a function of latitude in North and South America, with its minimum near the equator.

This figure illustrates also our finding that the variations in cosmic ray intensity are more closely correlated with the earth's average (or "geomagnetic") latitude than with the geographic latitude. Similarly Clay has found that the
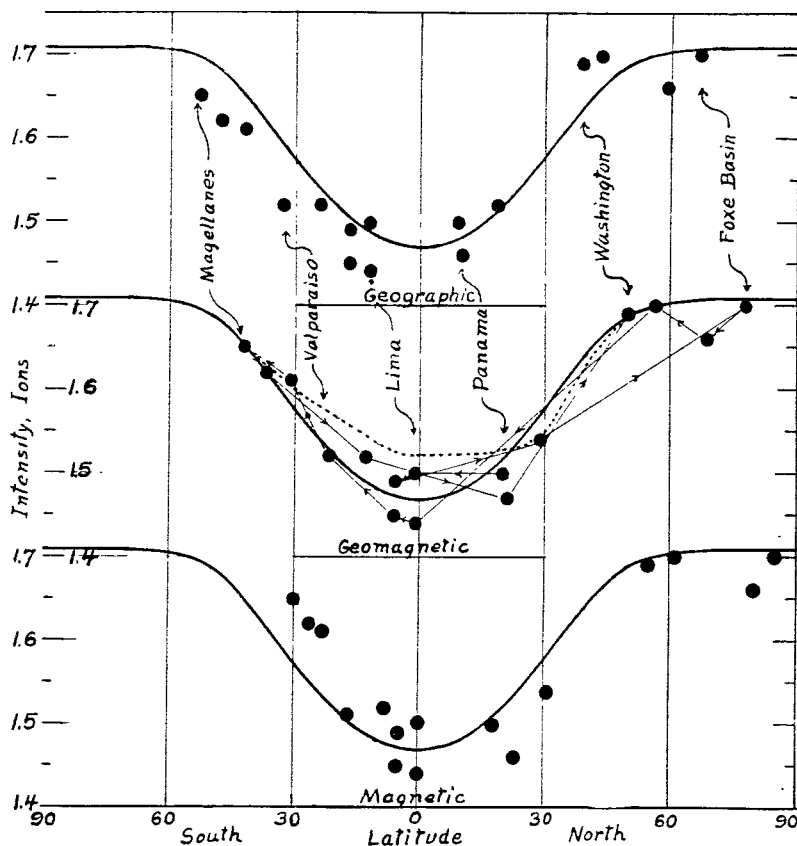
FIG. I.   Sea-level intensity in America as a function of geographic and magnetic latitudes.

decrease in intensity at the equator is more prominent at longitude about 110 degrees east than at 15 degrees west, in accord with the fact that the earth's magnetic field is stronger in the Eastern hemisphere.   Both of these phenomena have very recently been confirmed by the independent observations of Millikan and Neher.   Such details leave no doubt but that the latitude effect is due to the action of the earth's magnetic field.   The existence of the latitude effect accordingly implies that at least a considerable portion of the primary cosmic rays is electrically charged.

A most significant aspect of the latitude effect is its rapid
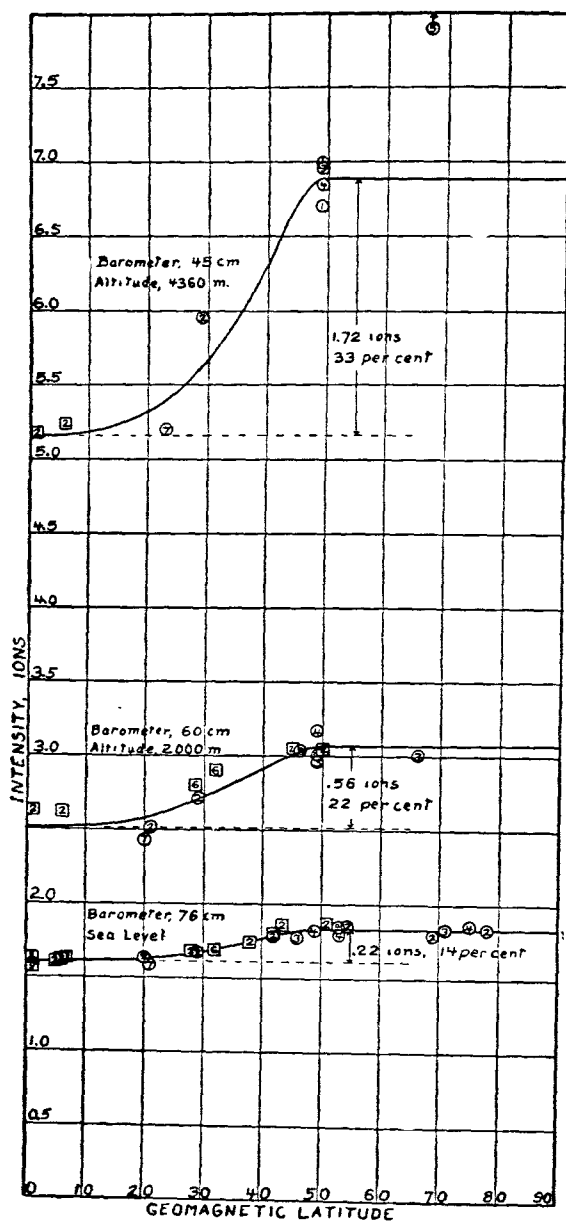
Fig. 2. Increase in the latitude effect with altitude as observed on mountains.

increase with altitude. This became evident from our high mountain measurements at different latitudes, as shown in Fig. 2, and has been extended to higher altitudes by the airplane measurements of Bowen, Millikan and Neher and of Clay, and especially by a comparison of the stratosphere balloon observations of Regener, Piccard and Cosyns, Clay, and Compton, Stephenson and Millikan. In Fig. 3 are
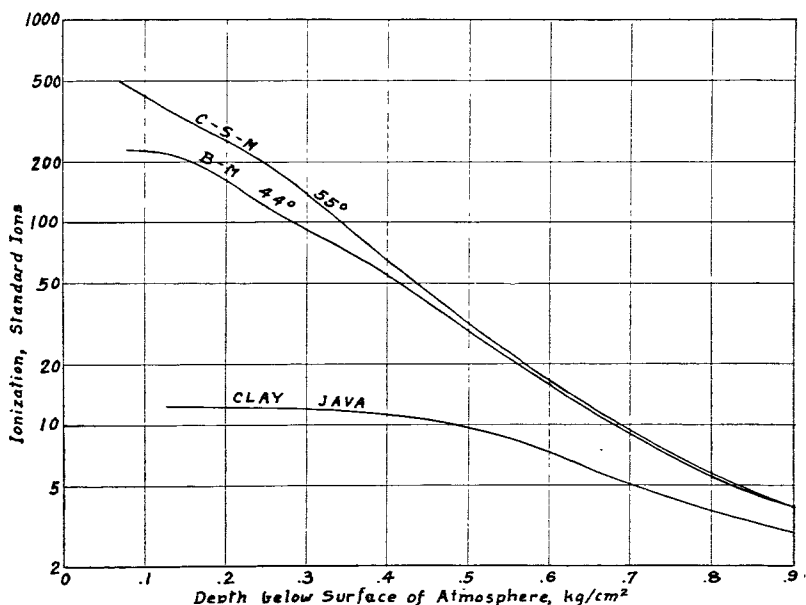
Fig. 3.   Ionization at different altitudes as observed using balloons at different latitudes, showing very large latitude effect near the top of the atmosphere.

shown some of these data. The striking fact appears that whereas at sea-level the latitude effect is only 15 or 20 per cent, near the top of the atmosphere the intensity observed by Clay near the equator at Java is only about 1/40th as great as that found on our Century of Progress flight in northern United States. This rapid change with latitude has been observed directly by Cosyns as he drifted southward in his Piccard balloon. At the surface of the atmosphere the ratio of intensities between the poles and the equator is certainly greater, and probably more than 100 to 1.

Since electrically neutral rays should be unaffected by the
earth's field, this result means at once that probably not more
than 1 per cent of the ionization at the top of the atmosphere
near the poles is due to electrically neutral rays.   It is within
the remaining one per cent of rays which reach the earth at
the equator that any electrically neutral primary rays must be
sought.

It has been found, however, that the rays at the equator
show a marked east-west asymmetry, indicating that the
earth's magnetic field affects a large portion even of the rays
received there.   Furthermore the rays reaching the earth at
the equator are absorbed in essentially the same manner as
those which are deflected by the earth's magnetic field.   Thus
in Fig. 4, curve *A* represents the absorption in the atmosphere
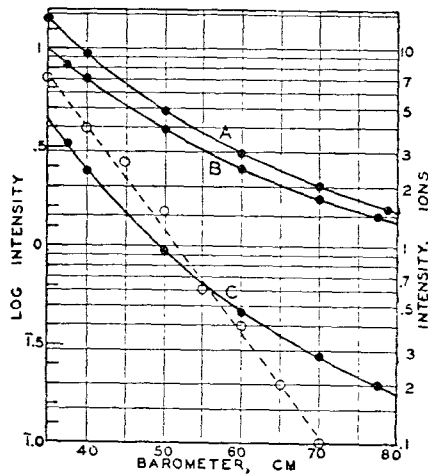
Fig. 4.   Curve *C*, representing absorption of electrical particles, is of the same form as
curve *B*, due to cosmic rays reaching the earth at the equator.

of the rays received at high magnetic latitudes, and *B* that
of the equatorial rays.   Curve *C* is the difference between *A*
and *B* and thus shows the absorption of the electrically
charged rays which are so affected by the earth's magnetic
field that they cannot reach the earth at the equator.   The
close similarity in shape of curve *B* which represents the rays
transmitted by the earth's magnetic field, to curve *C* which

includes only electrically charged rays suggests strongly that the two types of rays are of the same kind.

Additional light on the nature of the rays received at sea level is given by an extension of the experiments of Bothe and Kohlhörster. Modifications of their original experiment by Rossi and Hsiung seem to make the conclusion inescapable that the more penetrating rays at sea level consist of high-speed electrical particles.[1] A beautiful demonstration of this fact has recently been made by Auger who has arranged four counters in line with 50 cms. of lead between them and has placed an expansion chamber either above or below the lead. Expansion is made when a four-fold coincidence is observed. Out of 69 plates, 55 showed vertical trajectories of single, high-speed particles; 7 plates showed nothing; 6 showed oblique tracks of low energy and one showed a shower. The evidence is thus clear that such coincidences are due primarily to ionizing and hence to electrical particles of great penetrating power.

There is, however, another component of the cosmic rays revealed by these counter experiments. It has been shown by Rossi and Johnson that with increasing altitude the number of showers observed with counters out of line, as indicated in Fig. 5A, increases more rapidly than the coincidences due to high energy single particles as measured with the counters one above the other (Fig. 5B). This seems to require the assumption of an additional "shower producing radiation," which is more strongly absorbed in the atmosphere than are the corpuscles responsible for coincidences of the Bothe-Kohlhörster type. Experiments with counter tubes and cloud chambers agree in giving convincing evidence that the direct agent producing showers of corpuscles is a non-ionizing radiation, almost certainly photons. Rossi has shown, however, that these photons are themselves too strongly absorbed to be identified as a kind of primary cosmic rays. Anderson has observed cases in which the photons themselves originate

[1] These experiments and their significance have recently been discussed in detail by B. Rossi, Proc. London Congress of Physics (1934), and by A. H. Compton, Proc. Phys. Soc. London (Guthrie Lecture, 1935, in press).
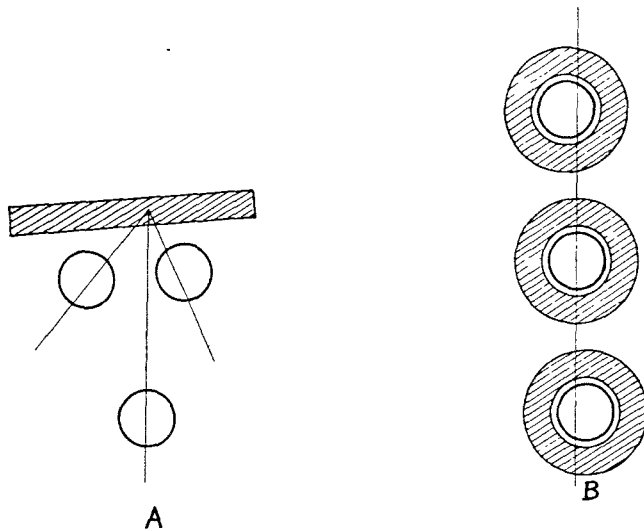
FIG. 5.   Arrangement of counting tubes to observe *A*, showers of particles, and *B*, highly penetrating particles.

only a short distance above his expansion chamber, and Johnson has shown that the shower producing photons are subject to latitude effect. Taken together these results point clearly to the view that the primary ray responsible for these showers is an electrical particle, very probably an electron, which on traversing matter produces photons just as X-rays are produced at the target of an X-ray tube. Only in the present case groups of photons instead of single photons are emitted. Each photon may when it is absorbed give rise to a shower of positive and negative electrons—a form of photoelectric absorption. Thus the increased relative number of showers with increasing altitude means that the primary electrons which give rise to the shower producing photons are themselves more strongly absorbed than are the coincidence particles of the Bothe-Kohlhöster type. This view reconciles the photon nature of the shower producing radiation with the existence of a latitude effect. Moreover as far as we can now tell the two types of primary rays included in this interpretation, both of which are electrical, are sufficient to account

for the observed characteristics of the sea level rays at all latitudes.

Other lines of evidence such as the strong east-west asymmetry found by Rossi for the coincidence producing rays that penetrate 8 cms. of lead, the independence of the transition effect of latitude, etc., give additional strong evidence that the various components of cosmic rays which are now recognized are due to electrically charged primaries. It seems unnecessary, however, to elaborate the argument further. If any electrically neutral particles such as photons or neutrons are present in the primary rays, they can constitute only a small fraction of a per cent of the rays entering the surface of the atmosphere, and at sea level are of too low intensity to show themselves in comparison with the more copious rays due to electrically charged primaries.

Analysis of the Primary Cosmic Rays

Our problem is thus reduced to that of identifying the various electrically charged components which may be present in the cosmic rays incident upon the earth. For particles of lower energy, such an analysis may be performed by using a mass-spectrograph in which electric and magnetic fields are employed. Attempts to deflect cosmic rays with laboratory electric and magnetic fields have recently met with some success. The energies of the primary particles are however so high that they are deflected only with the greatest difficulty, and even when this is done, it is hard to distinguish between the primary cosmic ray particles and the secondaries excited within the atmosphere. Fortunately however Nature has supplied us with a ready-made magnetic spectrograph suitable for analysing the primary cosmic rays. The earth itself acts as the magnet, and in place of the electric field we have the stopping power of the earth's atmosphere. This natural instrument has the advantage of such great dimensions that the rays are analysed far above the atmosphere, where they cannot become confused with secondaries. It leaves something to be desired regarding the uniformity of its magnetic

field, and we have not as yet been able to learn accurately the calibration curve with which to determine the energies of the particles in terms of their penetrating power in the atmosphere. In spite of these limitations and even with the incomplete information now available, an attempt to analyse the components of cosmic rays with our earth magnet leads to valuable results, and indicates the kind of data that must be obtained if such an analysis is to be made more rigorous.

This method of magnetic analysis consists in comparing the calculated minimum range of various types of particles which will be transmitted by the earth's magnetic field with the observed minimum ranges found from measurements of the intensity of the cosmic rays at different altitudes. It is found that the calculated minimum ranges for alpha particles, electrons and protons correspond to the observed ranges of three distinguishable groups of cosmic rays. Though the uncertainty in the comparison is at present unfortunately large, results indicate that the method should eventually give us a complete and reliable analysis of the primary cosmic rays

In order to calculate the minimum range of a particle at a given latitude, we first find from Lemaitre and Vallarta's theory the minimum energy required to traverse the earth's magnetic field. By a combination of theory and experiment it is possible to estimate the range in the atmosphere corresponding to this minimum energy. Thus in Fig. 6 is shown a family of approximate curves, for electrons, protons, alpha particles and oxygen atoms, which express the ranges of these particles in terms of their energies. We unfortunately do not know this range vs. energy relation accurately, and this curve accordingly is at present the weakest link in our analysis. However with the recent experimental data of Anderson and others, combined with improved theories such as that of Bethe and Heitler, such curves are sufficiently reliable to give significant results. Using these curves, we find for the minimum ranges corresponding to Lemaitre and Vallarta's minimum energies the values shown in Fig. 7. Thus at 52°, the geomagnetic latitude of Philadelphia, we predict a proton
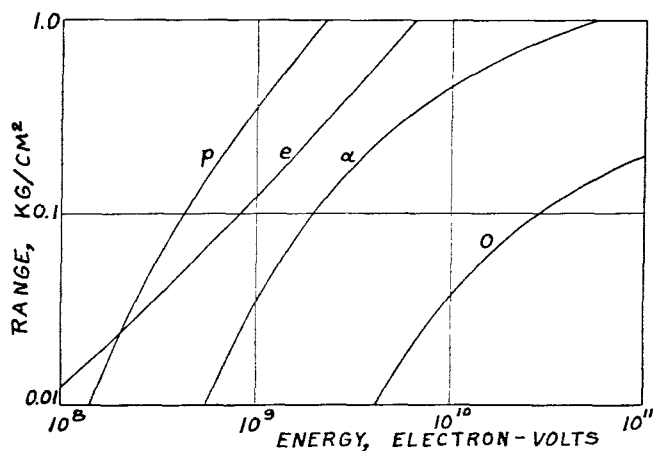
FIG. 6.   Estimated relationship between range in air of various particles and their energy.
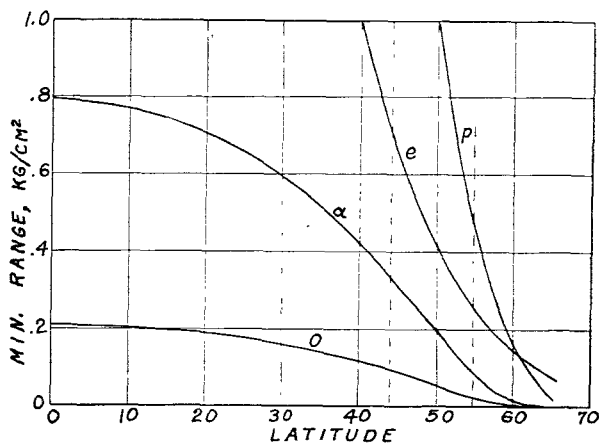
FIG. 7.   Estimated minimum ranges in air of the rays transmitted by the earth's magnetic field at different latitudes.

range of nearly an atmosphere, an electron range of about 0.4 atmosphere, etc.

The experimental values of the minimum ranges are found by an analysis of the observed altitude vs. ionization curves, using a method developed chiefly by Gross. In Fig. 8 is shown a typical curve of this type obtained on our Century of Progress balloon flight using a cosmic ray meter shielded with
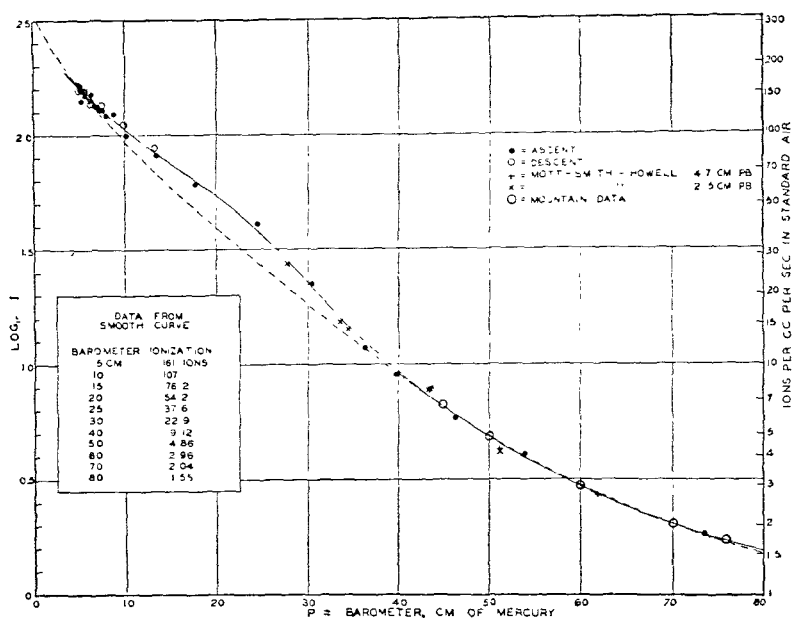
F<small>IG</small>. 8. Ionization as function of altitude using shielded chamber on Century of Progress balloon flight.

lead. The broken line represents the calculated shape of the curve if the ionization were due to "exponentially absorbed" rays. The departure of the experimental curve near 20 cm. of mercury pressure is shown on analysis to be ascribable to a range minimum in the cosmic rays.

Imagine, as in Fig. 9·A, that if the earth were unmagnetized the number of particles striking the atmosphere with a range r would be expressed by the broken curve. If only those with ranges greater than $r_{m\,n.}$ are transmitted by the earth's magnetic field, the range distribution would be that shown by the solid curve. If these particles come down vertically through the atmosphere, the ionization at a depth z below the surface will be proportional to the number of particles having a range greater than this amount. We thus obtain curve 9B. Taking now into account the fact that the particles strike the atmosphere not vertically, but uniformly from all directions, the ionization at depth z is found to be

about as shown in Fig. 9C. Here the knee of the curve marks the location of the range minimum. Similarly if the vertical rays consist of several components each with its own range minimum, the resultant curve should be the sum of several curves of type 9C.
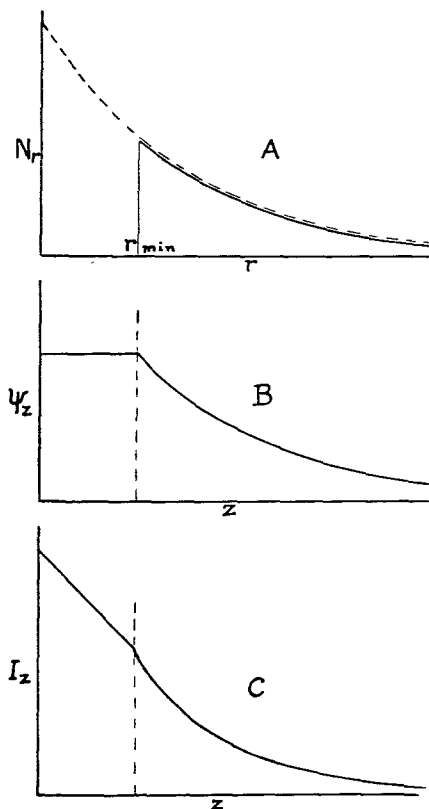
FIG. 9. Curve C represents the type of altitude ionization curve to be expected for particles the ranges of which are given by the solid line of curve A.

Returning to Fig. 3 we see a set of experimental curves which bear a marked similarity to that of Fig. 9C. Thus in the 44 degree curve there appear to be two breaks, one at about 0.14 and the other at 0.45 kg./cm.² Gross has shown how by analysis of these curves the range distributions can be directly determined. The expression for the ionization at

the surface of the atmosphere, due to the rays having ranges between r and $r + dr$ is

$$Rdr = - z \frac{d^2I}{dz^2} dr.$$

where I is the observed intensity of the rays at depth z. Applying this expression, we obtain corresponding to the experimental curves of Fig. 3 the range distribution curves of Fig. 10. The similarity between the form of these curves and that of Fig. 9.1 is as close as could be expected.

In this figure (10) are marked also the predicted ranges for the various latitudes for each of the four types of particles.
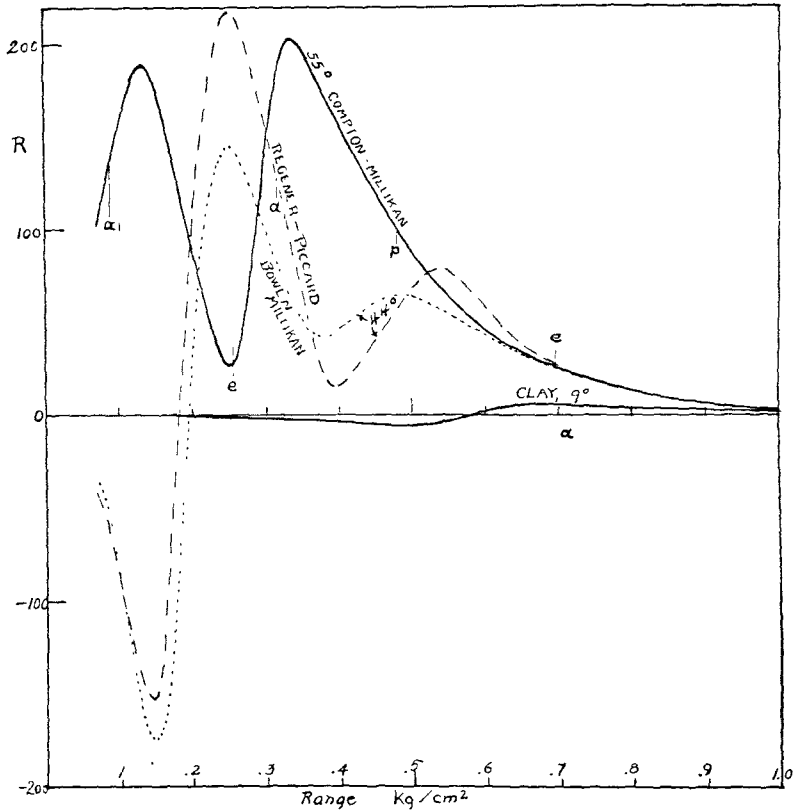
FIG. 10. Range distribution of cosmic rays calculated from balloon data taken at different latitudes.

It will be seen that for the 55 degree curve the alpha particle
limits and electron limits seem to be identifiable with the
two experimental range minima found at the higher latitudes.
Oxygen nuclei have ranges too short and protons have ranges
too long to be responsible for either of these two groups.
Though the agreement is not so good for the 44 degree curves,
this difference is of just the type to be expected because of the
irregularity of the earth's magnetic field and the uncertainty
of our energy vs. range relationship.

From data such as shown in Figs. 1 and 2 it is apparent
that some latitude effect is observable at sea level up to at
least 50 degrees. According to the curves of Fig. 7, however,
we find that electrons which reach the earth at sea-level (1
kg./cm.) should not be affected by the earth's magnetic field
above about 40 degrees latitude, whereas the predicted limit
for protons is about 50 degrees. The latter value fits so well
with the observed knee of the latitude effect curve that we
may reasonably conclude that the latitude effect found above
40 degrees geomagnetic latitude is due to protons.

Such an analysis thus leads us to distinguish three com-
ponents, which may be called *A*, *B*, and *C*, in the order of
their absorbability. Comparison with the calculated range
minima enables us to identify component *A* with alpha
particles, observable only in the upper atmosphere, *B* as
electrons, positive or negative, which penetrate the at-
mosphere with difficulty, and *C* with protons, which at the
latitudes studied have range minima greater than the thick-
ness of the atmosphere.

In judging the reliability of this analysis, two major
questions arise: 1. Are the breaks in the experimental depth-
ionization curves which we interpret as range minima, real
and reproducible? 2. If real, is our calculation accurate
enough to make the identification of the various components
unique?

To the first of these questions I believe we are justified in
replying definitely, yes. I have myself examined all the
balloon data that have been published in sufficient detail to

carry through an analysis of the type here presented, and find
without exception evidence of these breaks, at altitudes
corresponding to the latitude of the flight. Similar analyses
have been carried out by Gross on Regener's extensive data,
and by Cosyns on his own data and those of Piccard, in both
cases with results in satisfactory accord with those here
described. In Fig. 11 is shown a typical set of curves, based
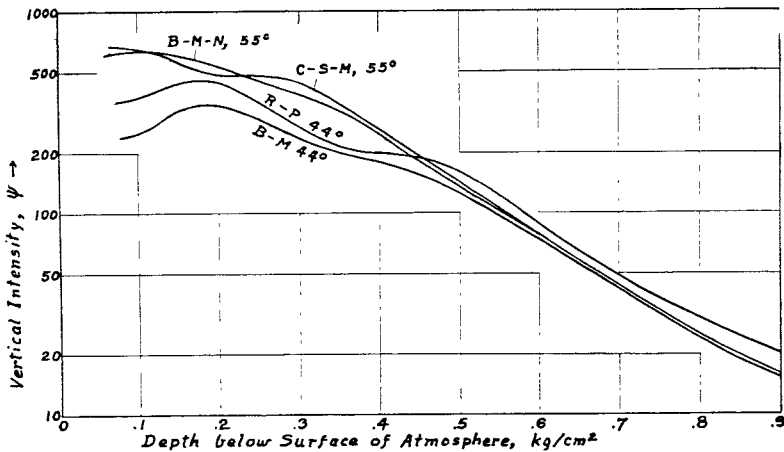
FIG. 11. Ionization due to rays coming vertically through the atmosphere, as calculated
from various balloon data.

on various sets of balloon flight data, analysed to represent
the intensity of the rays passing vertically through the
atmosphere. All show the breaks in question. I would call
particular attention to curve $M-B$, due to Millikan and
Bowen, and $B-M-N$, due to Bowen, Millikan and Neher,
both of which are taken from the smooth curves which they
draw through their data without recognizing any breaks.
A comparison of the $B-M-N$ curve with the $C-S-M$ curve
based on my line drawn through the same experimental
points shows the same breaks, only somewhat less sharply.

Regarding the reliability of the identification of the groups,
we cannot be so optimistic. I am elsewhere discussing this
question in detail.[1] Suffice it here to say that the uncer-

[1] A. H. Compton, loc. cit.

tainties involved in relating the energy with the range of particles and in the irregularity of the earth's magnetic field are enough to lay the results of our analysis somewhat open to question. Because, however, of the widely different predicted ranges of the various particles, we can have a certain degree of confidence in the identifications here suggested.

COMPARISON WITH OTHER METHODS

For components B and C which reach sea-level there exist several lines of confirmatory evidence supporting the identification of them respectively as electrons and protons. It will be recalled that directional coincidence experiments with counting tubes have shown a westward predominance, meaning that more positively charged rays reach the earth than negatives. Johnson has confirmed this result as far north as Philadelphia. Here, however, the limiting range of group B is far above the earth, and group C is the only one the directional distribution of which on hitting the earth can be affected by the earth's magnetic field. Thus it is this component which his experiments show to be positively charged, in accord with our identification of them as protons.

On the other hand, directional experiments at the equator, though showing an excess of positives, have been interpreted by Rossi, Clay, and Johnson independently as indicating also the presence of some negative particles. In fact, Johnson's recent studies have shown that the "shower-producing" component of the cosmic rays comes equally from the east and the west. This component is however subject to the latitude effect, and is accordingly electrically charged. Its symmetry in the east-west plane must thus mean that it consists of equal numbers of positively and negatively charged particles. Of known particles, positive and negative electrons form the only symmetrical pair which fit this condition.

This assignment of electrons, positive and negative, as the primary rays responsible for showers is exactly in accord with recent theories of the excitation of radiation by high energy particles, according to which photons, that form the

agent directly producing the showers, are excitable by electrons much more copiously than by protons or other particles of large mass. In fact, Bethe and Heitler conclude that photon production is the chief mechanism of energy loss by high speed electrons, whereas it is relatively unimportant for protons.

That the shower producing radiation is identifiable with our component B, of intermediate absorbability is indicated by Rossi and Johnson's observation that it increases more rapidly with altitude than do the penetrating particles responsible for the Bothe-Kolhorster coincidences which we should ascribe chiefly to our component C, *i.e.*, protons.

That we are correct in distinguishing two kinds of cosmic rays reaching sea-level is strongly supported by Eckart's recent analysis of the depth-ionization data into an absorption spectrum. The results of this analysis, expressed in terms of the intensity of the rays after penetrating 80 per cent of the atmosphere, are shown in Fig. 12. There is here a clear
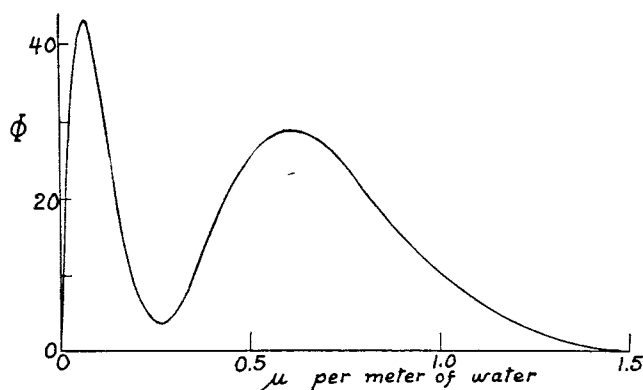
Fig. 12.   Eckart's analysis of the absorption coefficients of the cosmic rays which come vertically through 80 per cent of the atmosphere.

distinction between two components in terms of their absorption coefficients. The more absorbable one corresponds to our component B, and the more penetrating one to our component C. Component A, which is found from the stratosphere data, is so nearly absorbed at the depths considered in this analysis

that it cannot appear. If on the other hand Eckhart's analysis were carried through for sea-level, component C would be more intense than component B.

There is here, however, a difficulty that must be mentioned. We have identified group C with protons, and these should at sea-level form the major part of the primary cosmic rays. Cloud expansion experiments however reveal protons only rarely. Why are they not more frequently observed?

A partial answer is supplied by noting that a proton track can be distinguished from an electron track only when it is moving slowly enough to produce more ions per cm. than an electron with the same curvature in the magnetic field. If we assume that this difference becomes distinguishable when the proton is moving with less than half the speed of light, this means that only those protons with energy less than about 1.6×10^5 electron volts are identifiable by this method. From the penetrating power of component C it can be calculated however that the average energy of a proton which constitutes such a ray must be of the order of 10^{10} electron volts. Thus we should not expect more than 1 in 50 or so of the protons to be distinguishable from electrons.

Another factor is that component C shows a latitude effect at all latitudes where expansion chamber studies of cosmic ray tracks have been reported. This means that at these stations all the rays which reach the earth through its magnetic field have more than enough energy to pass vertically through the atmosphere. Thus, wherever the experiments are so controlled as to record only the vertical rays, no slowly moving protons should appear.

This deduction is in apparent accord with some recent observations by Anderson. He reports that whereas the lower energy tracks are about equally divided between positives and negatives (hence presumably electrons), there appears to be an excess of positive particles among those having more than 10^9 electron volts energy.

GALACTIC ROTATION EFFECT

Finally permit me to call attention to a phenomenon which seems to be quantitatively explicable in terms of the composition of the cosmic rays that has been suggested, but is difficult to reconcile either with the assumption of any considerable neutral component or of wholly positively charged primary cosmic rays.

Various considerations, such as the fact that the cosmic rays come from high altitudes and approach the earth nearly uniformly from all directions, inspired Millikan to suggest that they come from remote space, far beyond our galaxy. Recent studies, such as the latitude effect, have supported this view. Due to the rotation of our galaxy, the sun and the earth with it are moving, according to the work of Stromberg, Hubble and others, at about 300 Km. per second toward within a few degrees of 47 degrees north and right ascension 20 h. 40 m. Due to this motion, of about 1/1000th the speed of light, if the rays originate outside of the galaxy, the front of the earth should meet more cosmic rays than the back. Straight-forward calculations, which Mr. Getting and I are presenting elsewhere,[1] show that when account is taken of the increase in the number of rays received and their increase in energy and corresponding penetration, the ionization observed at sea-level due to this motion should be 1.2 per cent greater on the front than on the back of the earth. This calculation assumes no effect due to the earth's magnetic field, and should be directly applicable to any photon component of the primary rays.

The only data for testing this prediction which are at all adequate are the long-time continuous records that have been analysed to reveal any possible diurnal variation with sidereal time. The best set of such data as yet published is probably that of Hess and Steinmaurer, and is shown in Fig. 13. This figure shows the average, taken over a complete year, of the intensity of the rays as observed for successive half hour and

[1] A. H. Compton and I. A. Getting, *Phys. Rev.* (in press).

three hour intervals.   A diurnal sidereal variation is clearly shown, which is about 10 times the probable error, and whose maximum occurs very close to the predicted time.   The observed difference between maximum and minimum is however only 0.08 per cent, whereas after taking into account the latitude of Hess's observing station, the predicted difference, should have been about 8 times this amount.   Comparison with the published data of Steinke and new data by Hess which he has kindly sent me privately, confirms the existence of this effect, but on the whole indicates an even smaller amplitude.

This means that if the primary cosmic rays are photons coming from intergalactic space, there should occur a diurnal variation with sidereal time about 10 times as great as the observations show.

If however we assume the electrical composition of the primary rays that has just been suggested, the effect of the earth's magnetic field will be such as to reduce the diurnal effect to about the observed magnitude.   At the altitude of Hess and Steinmaurer's observatory (2300 meters) Eckart's analysis shows that about 60 per cent of the cosmic rays are of type *B* and 40 per cent of type *C*.   We have seen that component *C* is subject to a latitude effect, and is thus strongly affected by the earth's magnetic field.   Considering the highly complex orbits which Störmer's analysis shows for electrical particles in the earth's field, any maximum shown by this component should be very diffuse, hence of low amplitude, and of doubtful phase.   Of component *B*, however, only the fastest particles are able to traverse the atmosphere, and these will not be so strongly affected by the earth's field. The corresponding maximum should thus be more prominent. We have given evidence that this component has equal numbers of positive and negative electrons.   Because of this symmetry of sign, the phase of the maximum should be the same as for uncharged rays.   The only effect of the earth's field should be to reduce its amplitude.   From such considerations we have predicted a variation with about the same phase

as for uncharged rays, and with a difference between maximum and minimum within a factor of about 2 of 0.1 per cent. This prediction is shown in Fig. 13 as the sine curve. The agreement with the observations is really better than could have been hoped.

Though more and different observations are needed before this effect due to the rotation of the galaxy is established and understood, the evidence here given strongly supports the
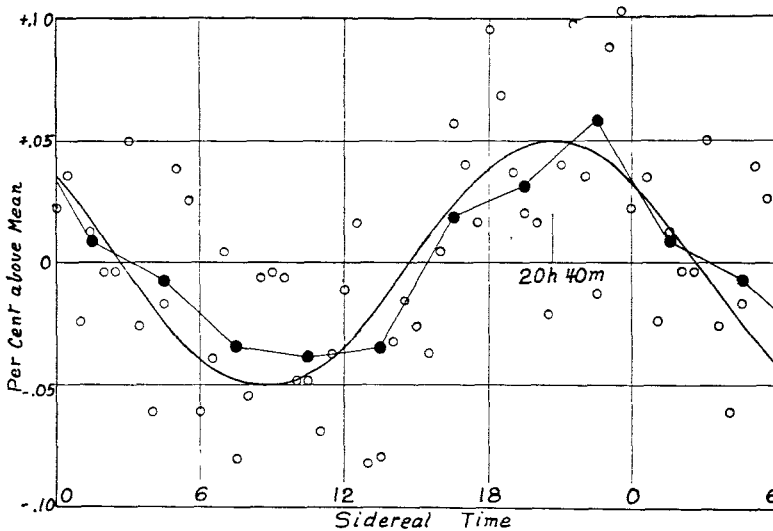
FIG. 13. Diurnal variation of cosmic rays with sidereal time. Data, Hess and Steinmaurer; sine curve, calculated from effect of rotation of the galaxy.

view that the cosmic rays do indeed come, as Millikan long ago suggested, from outside the Milky Way. On the other hand its amplitude is far smaller than it should be if the cosmic rays are electrically neutral, and the phase of the observed effect indicates that it is due chiefly to rays having equal parts of positive and negative charge. This as we have seen supports our identification of component B as electrons.

CONCLUSIONS

Measurements of the latitude effect at very high altitudes thus indicate that probably not more than one per cent of the

cosmic ray ionization as measured near the magnetic poles is due to electrically neutral particles.

At sea-level, counting tube measurements by Rossi and others reveal the presence of two distinct types of cosmic rays. One consists of highly penetrating electrical particles, and causes coincident impulses between counters placed in line. The other produces showers of absorbable particles, and apparently consists of photons. Both components show a marked latitude effect. The photonic shower-producing radiation is thus considered as a secondary radiation excited by charged particles (probably electrons) as they traverse the atmosphere. The penetrating coincidence particles on the other hand appear to be primary protons and electrons.

The analysis of the cosmic rays with our mighty mundane mass-spectrograph indicates the presence of three groups of particles, characterised by having at a given latitude three distinct minimum ranges. The three range groups are designated A, B, and C in the order of their ranges. Best agreement between the minimum energy admitted through the earth's magnetic field and the minimum observed ranges is found if group A is identified with alpha particles, B with electrons, and C with protons. When the evidence from directional experiments is considered, it appears that group B is probably composed equally of negatrons and positrons. There is no evidence for anything heavier than alpha particles.

This analysis, while tentative because of the rather large uncertainties in our knowledge of the relationship between range and energy, seems to agree well with the information supplied by other methods. Thus the directional experiments of Johnson, Rossi, Clay and others point definitely toward a proton component and a positron-negatron component in the rays near sea-level. Anderson's cloud chamber study of the sign of high energy particles fits with the same interpretation. The apparent effect due to the rotation of the galaxy is much too small to be ascribed to photons coming from outer space, but agrees well with a prediction based upon the electrical composition of the cosmic rays here assigned. No independ-

ent method of identifying component A seems to have appeared.

We may thus conclude with considerable confidence that the primary cosmic rays reaching sea-level consist almost wholly of protons, and positive and negative electrons. At high altitudes there is another component which seems to consist of alpha particles.

THE REVOLT AGAINST TASTE

HARRISON S. MORRIS

WHEN a lady is low in health or spirits, or fails to get what she wants, it is often a resource to fall into hysterics—not to omit gentlemen, for they too assume the hysterics of the fist or gun.

And in a more gregarious way. there come into art and literature periods of hysteria formed by the morbid, the disappointed, the perverted, who fail to get what they want.

So far back as the days of Shakespeare there was a pompous sort of mania in letters called Euphuism. It entangled even the immortal bard himself. in "Love's Labour's Lost." And passing on to a later century poetry laced itself up in what Keats called

> "a schism
> Nourished by foppery and barbarism."

Each age has had recurring manias for its own heresies and for its own form of revolt against taste.

But the most extraordinary revolution yet experienced in letters is that from which we are just now emerging, a senseless, incoherent. insolent attack upon Beauty and Truth, equal to the hold-up of the contemporary gangster.

As you look intelligently back along the processes of art, such moments in the grand development of man's creative gifts are minor both in matter and in consequence. In human efforts to seek unity with nature, all that lasts is the true, the genuine, the inspired.

The consciously eccentric poser who, like a pestiferous fly, is annoying but lasts only for a day, carries with him a thoughtless mob that wants excitement. This empty fuss seems to the untrained mind an evidence of quality, and thus we are obliged to behold literature in eclipse until the spirit of Truth recovers itself.

Through such a valley of the shadow we have been passing, not without explosions of wrath, though such were muted by the magazines and journals that follow the crowd for profit. Hardly a voice has been heard above the tittivations of poetic ladies who think poetry can be found in drinking tea, or accompanying Bridge.

The evolution of all arts is on a stem of an immovable tree whose roots are in the depths of the logical universe. The unfolding of art's beauty and truth can not be turned aside to suit the ignorance of the races who are under-bred. Yet such classes tell us that they have cast away tradition, they are superior to the fundamental laws, their aim is expression.

By expression, nobody can tell what they mean. Its meaning, if any, is as obscure as their productions. It may be guessed that they believe they are struggling for self-expression. But, even so, the self to be expressed in any art should be inspired with a passion for perfection. The sloppy, incoherent, meaningless jargon of their poetry and prose can convey only that the minds, or absence of minds, that form it are without the semblance of a gift for literary art.

Listen to this alleged poetry by Conrad Aiken, from a recent magazine. It is called "Escape the Pattern," and has all the trade-marks of its class. It would need a glossary to define what it is all about, except that the escape from a pattern may imply an aggressive originality in the author which neither he nor any of his class possesses. They all vociferously claim to be expressing themselves, and they all write the same sort of stuff. Here are the first and final lines of the precious composition:

"Escape the pattern to another pattern:
avoid the ending for another ending:
hate the face now, you fool, to love it later—
or love it now to hate.
     ....
         Cry down to the dark
which is below you, and is waiting for you,
and ask her for an answer. She is a pattern
begot of patterns and begetting patterns;
mad beyond madness; will tease you on
from false to false forever."

This so-called poem, in an effort to be self-expressive, omits capitals from the beginning of its lines; so does every versifier of the cult of obscurity. It asserts incoherence with a gravity that puts the reader on the defensive. So it is with every other member of this strictly original mob. It calls the manufactured lines "poetry"; though they have no resemblance to the noble art that comes down to us from Shakespeare and Wordsworth and Keats and Emerson. In fact it is not poetry, neither are the producers poets. Their asserted self-expression is a collective bluff.

If one were asked to prescribe for the ailment that these people who call themselves poets all suffer in common, I should think sound judgment would order a sense of humor. They take themselves seriously. There is not a flick of humor in scores of them.

Here is an example quoted by the Reviewer of the *London Times Literary Supplement*. He is cautious, because the conspiracy of publishers and poets is so subtle, but he can not conceal his sense of fun.

> *Thirty Pieces.* By Sydney Salt:
> Saul, speaking in one of these verses to the Witch of
>   Endor, asks:

> "Am I stammering to you of new worlds unconquered?"

And the reader of these thirty short and enigmatic pieces will feel inclined to address the same question to Mr. Saul himself. "The Sword" is a characteristic example:

> I draw this courtyard of my eye.
> He sits there,
> My eye stops seeing,
> I am fenced around it.
> Now this story
> Was when swords were humble; but now
> I shall lose my life.

What happens to the mind—or what he is pleased to call his mind—of the writer of such crazy sentences it is hard to analyze. It may be the urge to write, without adequate mental harness, or it may be the little child's naughty wish to startle. But whatever it is in the alleged poet, there is no

explanation of the motives of the publisher. One would expect him to be governed by the wish of profit; but only a business man as mad as his poet could be so deceived.

Yet this does not follow with the exaggerated volumes which we have had thrust at us in most reviews. They have had endless publicity and must have been reeking with profit. So much so, that nearly all our periodicals and newspapers have thought it prudent to print only the most bizarre and incomprehensible jargon as poetry.

Notably, this accusation may be pointed at the *New York Herald-Tribune*, which prints a column every Sunday, on its editorial page, of the least intelligble and most inconsequential verse that can be culled from the little monthlies—born of the present mania—not without an eye on profit.

And, yet, to prove that there is just as much high taste for genuine poetry, serious and comic, as ever; that same paper is graced by the editing and the poetry of F. P. A., in his daily "Conning Tower."

That his sense is as sound as his taste, may be gained from some of his droll paragraphs. This one, dealing with the most circulated offender, is characteristic:

> "In yesterday's *Times* Mr. John Chamberlain calls Mr. Archiblad McLeish 'the man who is, perhaps, America's foremost practicing poet.' For Mr. McLeish we have affection and admiration; but we wish he would quit practicing and get down to playing."

Listen to a sample of McLeish. He has no doubt of his divine calling. "This book is not a 'collected edition' of my poems nor does it purport to trace my development as a poet." He opens with a long harangue in a sort of metre, called "A Hamlet of A. McLeish." He mingles words of Hamlet with his own. What it is all about, I fail to divine.

> "We stand in the still earth and the sun comes
> Swelling among us with large light, with the
> Browsing of bees about him, with flattering
> Tree sound. He is tall. He reveals the
> Dark to us (He is informed in these matters)
> 'Behold!' he mouths in the gilt twigs.
> He advises our souls with the blabbed loose

> Light over water. He declaims the spangles of
> Glass in the high ways. He reproves us with
> Shining. Ho, he repeats the proverbs of
> Brisk leaves to enliven the laugh in us.
> He lays his hands on our sex to persuade us of
> Happiness under the sea noon.
>> How is it that the cloud still hangs on thee?
>> Why seems it so—particular—with thee?
>>> Seems, Madam! . . .
> Ha, we are preached by the
> Loud mouth, by the blooming of brightness.
> 'Cease,' he instructs us, 'to feel the emotions of
> Misery! Be bright boys! Console yourselves!' "

But you will be told that an epic of the same author, "Conquistador," expiates all his sins. I am without space to quote from it or to dwell on its freak typography; but it marks a practice of this cult of versifiers which helps to explain their currency.

If you put the great stories of the world into Yiddish, or Esperanto, or eccentric tricks with type, they will still be great stories. They can't be lost even in the incoherency of Amy Lowell or of McLeish. Thus Amy Lowell chose the amours of Lord Nelson and Lady Hamilton for treatment in her "laboratory of poetic research"; and McLeish has taken the immortal history of the Conquest of Mexico.

Most people are ignorant of Bernàl Diaz and his romantic and tragic book that lays open the drama of Mexico's conquest. It is thus quite safe to turn it into lines without beginning capitals, centrifugal words that fly off the text like radiations, affectations of style, and to do with it whatever the impulse to self-expression excites. The great central human story can not be destroyed.

In a mood of distraction over the poetry served up to him, one reviewer cries:

"Could he not have said it as imaginatively and more clearly in prose?"

and this thought persists in the reading of "Conquistador"; except that it had already been said in enduring prose by Bernàl Diaz.

I have dealt only with the alleged poetry of our unhappy

literary period, because to venture into its prose would take
us too far afield.   It would take us into journalistic novels,
into the muck of Freudian sexuality, into Joyce and Lawrence
and Dreiser, and lose us in the multitude of its mediocrity and
its inanity.

Only one small sample of the prevailing form may be
given as an index of all.   An educator, as they are now called,
recently felt his superior culture by inditing thus:

"Achievements of minimal requirements of units of study."

Illuminating phrase!

And illustrating the Revolt against Taste in words of one
of the most extreme examples of the insurgents, I close with
Lewis Mumford's polite estimate of Louisa Alcott.   He
scorches the paper thus:

> "Louisa Alcott was a hack writer purveying lollypops
> and chocolate cordials to the middle-class market."

Throw away tradition; deride taste and beauty, desert do-
mestic life, join the nudists of art and literature, and you will
be a big bold self-conscious and naughty best-seller.

THE FURNESS VARIORUM SHAKESPEARE

M. A. SHAABER

THE project on which I am to report, the Furness Variorum Shakespeare, has been under way for seventy years and it is not likely to be finished in much less than twenty more. Half-finished as it is, it enjoys a world-wide reputation, and in its own field it is unrivaled. It is indispensable to all students of Shakespeare and its name, at least, is known to all other educated men and women. It is, however, a labor of compilation rather than of original research; it aims at a synthesis of the results of the research of others without specially adding to those results. Therefore, since there are no new or precise findings which I can foreshadow, I think I could use this opportunity to the best advantage by explaining somewhat the history of the Variorum Shakespeare and the part which the assistance of this society is playing in keeping it alive.

It was soon after the end of the Civil War that Dr. Horace Howard Furness the elder, then in his early thirties, finding that growing deafness disqualified him from pursuing the profession of the law, turned to the study of Shakespeare and of Shakespearian scholarship, which had strongly attracted him almost from boyhood. Dissatisfied with the apparatus for the study of the plays then available, he planned a new edition on a scale as yet unattempted. An ordinary critical edition, the kind in which we usually read Shakespeare, is the work of one editor, who arranges the text as he thinks Shakespeare wrote it and adds whatever notes, comments, and illustrations he chooses to assist the reader's understanding and enjoyment. Up to 1870 about thirty-five important critical editions of the works of Shakespeare had been published; there are now possibly fifty-five or sixty. Of course, they differ considerably in detail, especially in emending

difficult and seemingly corrupt passages and in interpreting
the characters, the action, the thought, and the imagery of
the plays; taken together, they provide an almost bewildering
mass of comment and explanation, fascinating to the scholar
and suggestive to even the ordinary student.   It was Dr.
Furness's interest in the divergences of the comments of the
editors and his belief in the virtue of a comparison of their
opinions in throwing the strongest light on every phase of
Shakespeare's art that moved him to plan a *variorum* edition
which would include the readings and elucidations of all the
editors and critics and thus put in the reader's hands the final
results of all the study and investigation that had been
bestowed on Shakespeare's works.   That is what the New
Variorum still aims to provide—a summary of the materials
which students of Shakespeare have assembled to assist our
understanding and enjoyment of the plays.

The success that Dr. Furness's work met with is something
which I need not explain to a Philadelphia audience.   While
he lived, Philadelphia was perhaps the best-known center of
Shakespeare study on this continent and his edition is still
America's most distinguished contribution to Shakespeare
scholarship.   The usefulness of his comprehensive method,
the reliability of his accurate workmanship, the wisdom of his
judgment, and the charm and wit that lurk in every expression
of his own thought and feeling are proverbial.   And by a
chance almost unique in the annals of scholarship, he found a
successor in his own son and namesake, who, working at first
side by side with his father, carried on his labors for seventeen
years after his death.

It was evident, however, to the younger Dr. Furness, some
time before his death, that he could not live to finish what his
father had begun.   By 1928, when he published his last
volume, he and his father had issued nineteen plays, half of the
total of thirty-seven that comprise the accepted canon.   Dur-
ing his last years the thought of passing on the trust which he
had received from his father often crossed his mind.   About
1921, Professor Samuel B. Hemingway, of Yale University,

who had recently edited *1 Henry IV* in the Yale Shakespeare
series, wrote Dr. Furness urging him to take up this play next
and offering some textual notes which he himself had made.
Dr. Furness then suggested that Mr. Hemingway proceed
with the collation of the texts, with the idea of preparing the
commentary and appendix himself.   When Mr. Hemingway
had finished the collation, however, Dr. Furness felt that he
was unlikely to reach that play and invited Mr. Hemingway
himself to prepare the commentary.   This play is now on the
verge of completion.

   About a year before his death, remembering the advice his
father had given him years back that if he ever got into diffi-
culties he should consult Professor Felix E. Schelling, Dr.
Furness asked Professor Schelling to suggest two young men
from the Department of English of the University of Penn-
sylvania who could assist him in his work.   Professor Schelling
named my colleague Dr. Matthew W. Black and me.   Dr.
Furness invited us to become co-editors with him and assigned
us *Richard II* and *2 Henry IV* to work on.   We were working
under his supervision at the time of his sudden death in 1930.

   At this time, then, four plays (including *Henry V*, which
Dr. Furness himself had begun) were actually in process of
preparation.   We whom Dr. Furness had inducted into his
work felt that we owed it to him to carry it on; scholars
everywhere told us that so useful an undertaking must not be
allowed to lapse.   But we found our resources inadequate to
carry it on without help.   Dr. Furness and his son were gentle-
men of means, who could give the Variorum their undivided
attention and pay for the publication of their work out of their
own pockets.   Their successors were college teachers who
could give the Variorum only those rare hours of leisure which
their duties left them and who had no resources for financing
the publication of these sumptuous volumes.   Accordingly,
they applied to the Modern Language Association of America,
and through it to the American Council of Learned Societies,
for assistance.   In December 1932 the Modern Language
Association appointed a committee under the chairmanship of

Professor Schelling to consider this problem, and on its recommendation the association undertook the sponsorship of the whole project, appointed Dr. Joseph Quincy Adams, the director of the Folger Shakespeare Library in Washington as general editor to supervise the continuation of the work, and assumed responsibility for the publication of new parts of the series as completed. It was at this point, by a happy inspiration, that the committee of Shakespeare scholars which the Modern Language Association placed in charge of the work invited the American Philosophical Society to assist in carrying out its plans. I hope this society congratulates itself as heartily as the committee does on the singular appropriateness of this pious act by which the society agreed to help defray the expenses of carrying on a project which has so long done honor to Philadelphia and which was conceived and for seventy years carried out by two of its own members.

I should like to explain that the funds granted by the society have been used entirely to provide for work on forthcoming issues of the Variorum series. Inasmuch as Dr. Furness and his son, giving their full time to the work, produced, on the average, one play in a little more than three years, it was at once evident to the committee that some one who could give it at the most only one or two hours a day would require nearly a quarter of a century. It determined, therefore, to use the funds placed at its disposal to obtain full-time work. Accordingly it arranged with the University of Pennsylvania to grant a year's leave of absence to Mr. Black and to me, the university paying a part of our regular salaries and the committee the remainder. As a consequence of this timely aid, Mr. Black and I have been working daily in Dr. Furness's own library, which his son bequeathed to the University of Pennsylvania, on the work that he himself began, in a sincere effort to advance it as best we can with the resources at our disposal.

Under these arrangements, and with the Modern Language Association providing for publication of our work when it is finished, the continuance of the Variorum series is assured.

Three plays are under way: one of them can be sent to press within a few months as soon as the committee finds means of putting it through the last stages of the editorial process, and the others may be tentatively scheduled for 1938.   In addition, the committee is ready to put additional editors to work on new plays as soon as it can obtain the necessary backing.   It feels able to give assurances that the work it supervises will not be unworthy of the tradition established by Dr. Furness; that, if the requisite support is forthcoming, it can complete the series at the rate of one play every year instead of every three or four years; and that, in about twenty years, which is only a short time in the history of an undertaking on which two lifetimes have already been expended, it can set before the world a completed Variorum edition, a veritable monument of scholarship in which all concerned with it can take a justifiable pride.

THE PARADOX OF SCIENCE

EDWARD L. THORNDIKE

(Read April 18. 1935)

Intelligent men who know the facts of science have relinquished most of their hopes of supernatural control of the forces of nature. No matter how devotedly they worship their God, they do not ask him to turn men into animals, or send rain for the just and lightning against the unjust. No devil is blamed for sending a plague of infantile paralysis, and no deity is expected to remove it. Where bullets, blessed or unblessed, go is determined by the laws of ballistics. Whether a gift to a beggar will benefit or injure him is determined by facts of psychology and the social sciences, not by the blessing of the church. With few or no exceptions, nature takes its course undisturbed by vows, sacrifices, and prayers.

Science, studying the ways of nature, finds them to be so regular and reliable that the assumption that they are perfectly so has gradually become almost an axiom in science and its applications. In the faith that nature will not change her ways (or customs, or habits, or laws, or behavior in the frame of space and time, or whatever the reader likes to call them) bridges are built, trains are run, diseases are treated or prevented, crops are grown, children are taught. We no longer fear, as men once did, that the sun may not bring summer again. We do not pay sacrifices to control the seasons, but trust the uniformity of nature and our predictions of the earth's path for thousands of years. We have abandoned prayers to the goddess of fertility to bring the seed to harvest, believing that the same seed in the same soil with the same climate will always produce the same result.

Supernatural forces were often irregular and capricious. In spite of one's best efforts to induce them to act in a certain way, one might be outbidden; and sometimes all bids were

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rejected in favor of some darling of the gods.   But the forces known to science always produce the same result under the same conditions.

In human affairs precisely the same conditions rarely, if ever, recur.   Perhaps no two typhoid infections ever were absolutely alike; almost certainly no two cases of typhoid infection studied have been absolutely alike.   But pathology is confident that if identical bacilli invaded identical human bodies and were treated identically, the results would be identical.

There has never been another depression just like the depression of 1929–?; there has never been a war identical with the World War.   The situation of the world on January 1, 1935 never existed before and never will again.   There probably has never existed a single village the conditions of which were identical at any two moments; nor any two villages which were identical in nature.   Science cannot roll identical villages down a depression again and again to test the laws of economics as it rolls ivory balls down an inclined plane to test the uniformity of the laws of motion. But it has confidence that if the same human elements could be subjected to the same conditions, they would display the same outcome.   It believes that the same brain or mind acted upon by the same stimuli will give forth the same thoughts, feelings and acts.   Physiology and psychology use that belief just as physics uses the belief that the same mass at the same distance from the earth's center will, other things being equal, fall toward it with the same speed.

Nature's ways are not only regular; but to the best of science's knowledge and belief they are also immutable. Nature may add new customs if new things and conditions develop, but it does not change its customs of behavior with the same things and conditions.   Science expects the combination of oxygen and hydrogen to make water a million years from now if conditions remain the same.   If a certain equipment of genes under certain conditions of environment made John Doe born in 1900 a murderer, that same equipment

of genes in that same environment will make Richard Roe born in 1950 a murderer except for supernatural or extra-natural forces.

In proportion as power is taken from personal deities and lodged in the uniform and stable ways of nature, man abandons all appeals, bribes, and inducements such as might move a super-man who enjoyed material gifts, praise, submission, respect, or affection. It is more reasonable to find out the course of nature and make the best of it. Propitiation gives way to observation and prediction. Science aims to learn nature's ways so as to know what will result from any concatenation of events. The present goal of science is to understand and predict every event in the world as it can now understand and predict the movements of familiar heavenly bodies or the swings of a pendulum.

But, by a unique paradox, science, which finds nature's ways invariable and unchangeable, changes nature as the personal appeals of religion never could. Science, which accepts the course of nature, controls it to an extent and degree far beyond the powers of priests or magicians. Science can make lightning and direct its course; can stop plagues; can double a harvest; can breed new strains of animals (and of men, if human laws and customs would permit).

In proportion as we treat the world as regular and re-sistant to outside influences we influence it. If science in the next hundred years should describe the ways of human nature and behavior as accurately as it has by now described the nature and behavior of the planets and stars, so that man could predict what men would do as he now predicts eclipses, he would increase his power to control the fate of men. Every immutable "law" of human physiology and psychology would turn into an instrument to change human life. By the same token, if, by science, I could prophesy exactly what I would think or feel or do in every conceivable situation that life could offer, and knew that my thoughts and feelings and actions in each case were as inevitable as the pull of the magnet on steel, I would thereby enormously increase my

power to change my fate. Every fact of the universe which science takes from the realm of fortuity, miracle and caprice, and puts under the rule of the regular and changeless ways of nature, means one more addition to control over nature. The more the world is determined, the more man can work his will upon it.

The explanation of this paradox should be instructive and comforting to men and women who are disturbed because the march of science seems to reduce the world to a mere machine, to abolish the freedom of the will and eliminate human responsibility.

They have thought that the paradox was a dilemma—that if the ways of nature including human nature were invariable and immutable, then no acts of man could change nature— that one must choose between science and freedom.

The paradox is not a dilemma. Science does not necessitate fatalism. The uniformity of nature is consistent with changes in nature made by human thought and action, especially as guided by science itself. This is possible because science is a part of nature, because knowledge is a natural force, because human ideas, wants, and purposes are part and parcel of the stream of natural events. Your consideration of whether to say yes or no in certain situations is an event in nature. Your decisions yesterday to say No and today to say Yes are events in nature. Both have their consequences in perfect accord with the ways of nature. But your "No" of yesterday may have changed the world by the death of a prisoner whom you refused to pardon, and your "Yes" of today may have changed you from a bachelor to a husband and been a link in a chain of causation resulting in the birth of a child who in 1983 will discover a cure for cancer.

The essential facts are as follows: The course of nature is partly repetitive or cyclical, as in the movements of the planets or the turn of a motor, and partly original or creative, as in the development of a new species of animals, or the construction of the Panama Canal. The distinction is not,

however, sharp. Even the most repetitive parts may change. Indeed they must if conditions change. Even the most novel events consist of old elements in new combinations. The net total is a universe changing very little in some respects and very much in others, but surely changing from 100000 B.C. to now, and equally surely from now till tomorrow. Within the brains of men, the changes are so numerous and rapid that a year's crop within New York City alone could not even be listed by a thousand chroniclers in a life time.

Parts of the world change other parts. So changes in the moon will cause changes in the tides; the birth of a baby changes the habits of a household. Notable among changes of one part of nature by another are those initiated by changes in human brains. To them are due buildings, mines, farms, tools, and all the material paraphernalia of civilization; laws, customs, creeds, and all present forms of social institutions; schools, libraries, laboratories, and all the apparatus of science and letters.

The changes initiated in human brains are on the whole serviceable in satisfying human wants. Those which are outcomes of impartial scientific observation and inference discovering nature's ways, have been specially successful in satisfying human wants. They operate by changing his own behavior into forms more suitable to obtain satisfaction from the rest of nature, and by changing the rest of nature into forms that suit man's needs better. They work within nature, as regularly as any of its habits. Man is creative, not because he is in part supernatural or extra-natural and imposes a super- or extra-natural will on nature, but precisely because he is, in part or altogether, a natural object, linked in the chain of natural causation, and playing a role in nature's long drama. The fundamental basis of that drama may be very simple, nothing but moving electrons and protons which perhaps have always been and always will be the same, but its actual course is anything but the same from moment to moment. It constantly creates new forms for itself, and parts of it known as men share in that creation.

One need not be in despair because science teaches that the world is a great self-contained machine whose operation no god or devil can alter. If so, it is a peculiar sort of machine which alters itself and has produced the Divine Comedy, Paradise Lost, Beethoven's symphonies, and all the truth, goodness and beauty that man knows. If so, man is a part of it and is constantly altering it. His duty and his pleasure in respect of it will be much the same whether deities outside it are or are not active to help or hinder him.

No one should feel that any zest will be lost from life if science proves all of nature to operate according to regular customs so that an omniscient historian at the end of the world could honestly say that never had the same set of conditions failed to produce the same result. The zest of life does not consist in fortuity and ignorance of what will happen. It would not be increased, for example, if days and nights come by chance like the red and black of a roulette series. It is increased rather than lessened by the possibility of predicting what will happen in new situations from knowledge of the regular behavior of their components, provided there is enough novelty and surprise. There will be enough, surely, for the next thousand years, and probably forever. The discovery of nature's uniformities by science leads to creative action that increases the amount and proportion of novelty, surprise, and new discovery.

The threat of a universe without hope because the forces in it must inevitably determine every item of its future and produce results which an omniscient observer a billion years ago could have foretold is an idle threat. In the nature of the case there could not have been any such observer then or now. But if there could have been, and if he had left a record of what would happen until A.D. 10000, and if his record had been found in A.D. 1935 and verified as correct by the occurrences say to A.D. 1975, it would include the fact that science profited by it from 1935 to 1975 to increase man's control over the rest of nature and inaugurated the era about 1940 since known as the "Era of Hope" when man could foretell the

future and control his fate as never before. The best hopes we have are those got by the predictive power of science. Every advance in prediction means a gain in valid hope and a loss for disappointments.

No one need fear that science will diminish human freedom. On the contrary it greatly increases the only freedom that any reasonable being can desire. The freedom of the will has meant and still means different things, some of which are of no consequence whatever to human welfare, and some of which are highly undesirable. It sometimes means simply that there is a small margin of sheer chance or fortuity in the universe. For example, electrons might vary slightly one from another in unknown and unpredictable ways, but the total or average behavior of any atom composed of them might be perfectly regular and dependable. All our chemistry and physiology would remain true in spite of such uncertainty about the behavior of single electrons (or indeed of single atoms). A margin of fortuity in the behavior of electrons would be of no consequence in relation to the question of whether persons have a freedom of the will lacked by dogs and cats (or to any question about persons, dogs, or cats).

Another meaning locates this undetermined margin in the higher animals, especially man, asserting that human choices are occasionally or in part unpredictable, unaccountable. If this be so, it is regrettable, since it would be a cause of confusion and error. Occasionally the best of men might choose the worst of courses, or the worst of men upset reasonable expectations. Freedom is a bad name for it, for it would really be bondage to chance.

The doctrines of theology and of intelligent people in general are wisely not concerned with margins of fortuity or unpredictability, but with the freedom of a person from domination by circumstances, or with the freedom of some core or kernel of a person from domination by circumstances or by some more superficial and temporary features of him. There are many possible variations on this general theme.

Thus some would say that men are not the creatures of temporary circumstances, but bear, each within his own nature, tendencies to favor and cherish certain courses of thought and action and to reject or discard others. By birth and training, a man acquires a core of personality or soul which can dominate circumstances and change their consequences. Nothing in science denies this. It might deny that any extra-natural force implanted these souls in babies, crediting rather the genes in their chromosomes. Others would mean by the freedom of the will the power of a man's deeper self to direct his life with or against the pull of external influences, or superficial motives, or casual enticements. "I am the captain of my fate, I am the master of my soul." Nothing in science denies this. On the contrary, the more fully man knows the ways of nature, including human nature, the better able will his deeper self be to rule the external, casual, transient, and superficial.

Everywhere it is the same. Science transforms a world of fairies, demons, magic, charms, and luck into the dependable world of "natural law." Every addition it makes to its catalog of nature's changeless habits helps man to change nature, including himself. The uniformity of nature does not take power away from man, but from fortuity or chance and from alleged forces which operate partly or wholly by chance.

SOME REFLECTIONS REGARDING HUMAN HEREDITY

ALEŠ HRDLIČKA

In studies on man, wherever the worker turns, he is confronted with the three basic organic phenomena of development, heredity and variation. At the 1934 general meeting of this Society I dealt in brief with the subject of human variation; today I shall present a few remarks on human heredity.

Human heredity is surely nothing apart from organic heredity in general, yet seems to have various peculiarities of its own. It is, regrettably, not amenable to experiment; its study is complicated through man's extensive hybridism, his long life, the widely differing human environments, occupations and habits, through numerous poisons and extensive pathology, and last but not least by man's mentality; but it has some advantage in that it can intimately and over long periods of time be studied in the observer's own person, in his children and relatives and more or less also in his friends, in his and other ethnic groups, and in the human species in general. Such studies on humans are resulting in the growing recognition that the subject of heredity in man is even greater than was hitherto or is now generally appreciated.

Barring incidentals and purely individual or "environmental" acquisitions, an analysis of man's being and of the workings of his system fails to show a single feature, a single manifestation, that is not, at base at least, due to heredity. From his inception to his end, both materially and functionally, man—as every other living being—aside from the casual and environmental modifications, is the resultant of his heredity. In this light, the age-long problem of life itself appears to lose its distinctness. If, fundamentally, that is

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aside from purely individual acquisitions, all that an organism is physically and chemically, and everything it does physiologically and even mentally, is merely embodied and discharging heredity, then life becomes, it seems, inseparable from the kinetics of heredity, and the two terms become synonyms of one and the same great natural phenomenon. If this is wrong, then life must be some still unknown force, but one which has no means of manifesting itself except through and in accord with heredity and its modifications.

Other appreciations that present themselves from studies on man more perhaps than from that on other living beings, are, that heredity is not full-fledged and ready-for-work at any time of the existence of the individual, but that it follows a chronologically and otherwise strictly regulated course of fruition and emergence; that any portion of heritage once fully discharged does not repeat itself in the same individual; that the fixedness of the items of heredity is apparently proportionate to their antiquity; that, in a way, there exists not only individual, but also something like a family, race and even pan-human heredity; and that the emergence of heredity can be fostered, restrained, modified, or even stopped in its various items, through accidental and even voluntary agencies that come, or can be brought, to bear on the process.

A more intimate approach to these matters demands first of all as clear as possible a definition of heredity.

What Is Heredity?—The most current older definitions were that it was "the transmittal of parental characters," or the "hereditary transmission of parental characters to the offspring"; which says superficially what heredity does, but not what it is. Authors such as Davenport, in his once (1913) very good book on human heredity,[1] or Starling with Evans and Hartridge, in the latest edition of their *Handbook of Physiology* (1933), avoid their own definition. Valuable and largely original definitions are given by Conklin. There are two of them, one in the earlier and one in the latest edition of his excellent book on *Heredity and Environment*. They are

[1] C. B. Davenport, *Heredity in Relation to Eugenics*, N. Y., 1913.

much alike, yet somewhat differing, and it would almost seem that the earlier one was preferable. They read:

1918: Heredity may be defined as the particular germinal organization which is transmitted from parents to offspring; and,

1930: Heredity may be defined as the continuity from generation to generation of certain elements of germinal organization.

I have not found yet a succinct definition by Morgan. The latest edition of the Encyclopædia Brittanica defines heredity as "the resemblance between an organism and its ancestors, in so far as this resemblance is not due to similarity of environment"; and in the latest and very good textbook on *The Principles of Genetics and Eugenics*, by Faston (1935), it is simply "the resemblance between organisms related by descent." All of which is descriptive rather than analytical and falls short of an explanation. It evidently was and still is felt by many that heredity is one of those conditions which connect with the very fundamentals of living matter and the full understanding of which, as with other such fundamentals, is not yet attainable. Yet so much has been done in recent years in the clearing up of the subject that some closer approach to a rational definition may be possible.

Heredity can surely be no quantum or agency apart from the material constituents of the organism to which it belongs. It can only be, in its substance, the property and quality, or briefly constitution, of the ultimate organic elements that control development, and its workings can only be a function of these elements.

The ultimate such units, so far known or rather deduced, are the genes, which may provisionally be defined as the basic, relatively stable, mollecular clusters that embody, alone or with the help of the cytoplasm, all the transmissible properties of an organism—in other words all the heritage of the past; and which, through the discharge of this heredity, are capable of engendering and directing all the vital processes and developments in the body to which they belong. Heredity, therefore, collectively, is explainable essentially as both the property and the function of the genes; and any modification

in heredity implies then necessarily, in the main, a preceding, corresponding and transmissible modification in the genes.

The genes may now perhaps be defined most simply as the mollecular embodiments of heritage, and heredity as the principal function of the genes—or as the principal emergent potentiality of the genes. The workings of heredity can only be the totality of the continuous specific discharges of influence by the genes, modified by that of the varying cytoplasm and organization of the different cells. Heredity itself may now perhaps be most succinctly defined as the aggregate of the fixed and transmissible potentialities of the genes of an organism, and its workings as the progressive manifestations of these potentialities throughout the life of the individual.

The gene, in a rough way, may be compared to a man-made machine. If incidentally or designedly there is made any change to the effective parts of this machine, its products will henceforth bear the imprint of such a change; and if the machine could lead, as evidently the gene does, to an exact reproduction of its kind, the change made would become "hereditary."

The above plain conceptions, which I believe are now shared more or less consciously by all workers of experience in the field, are sufficient for an elementary view of the basis of heredity.

Complications.—The discharge of the potentialities of the genes is, however, according to indications, far from simple. The genes are a multitude in number, and what to the unaided senses appear to be a single feature, such as the color of the eye, the characteristics of the hair, the size and form of a part or an organ, respiration, circulation, procreation, memory, and every other function, is in reality a complex and in some cases a very high complex, in the production of which there is a cooperation of the potentialities of several to many genes. Whatever major feature or manifestation of a living body therefore is considered, such a feature or manifestation is primarily a resultant of the heredities of a group of related and cooperative genes. This introduces the first complication

into the picture of heredity, namely the phenomenon of aggregates and possibly systems of genes which involve cooperation, correlation, probably compensation, and other positive, with probably also neutralization, inhibition and other negative or restrictive phenomena. The laws that control these gene associations are as yet unknown and perhaps unapproachable.

Contending Heredities.—Connected in a way with the preceding yet quite distinct, are the results of the unions of differing parental heredities. Such unions in organisms with sexual reproduction are, of course, the rule, but nowhere are they as complex as in man. They bring together genes— heredity carriers—of differing, and at times or with individual genes greatly differing character, and there must be a great many differing reactions between such genes, with many differing results. If the genes blended or harmonized, matters would be simple, for the product would then be comparable to the mathematical resultant of the union of two quanta; the indications are however that a good many of the parental genes do not blend or harmonize but preserve more or less of their individuality and in instances even antagonism. The result in such cases is not the discharge of one fused but of two separate cœval heredities, which leads to complications. Some of the unblended or disharmonic genes in such cases are bound to be more potential or 'dominant,' some weaker and hence 'recessive.'

Many dominant and recessive hereditary items are already known in the subhuman organic forms, particularly in pigmentation and other features of the epidermal structures; in man their studies too have progressed, but are beset with greater difficulties. But there are probably all grades of dominance, recessiveness and antagonism between the heredity-potentialities of the genes, and the interactions of their discharges can only be viewed, it seems, as contending heredities. This notion is strengthened by the fact that during the life of the individual who in one respect or another carries such contending heredities, for a time one and after that the

other comes to predominate. There are many examples of this in man, in pigmentation, looks, behavior, character, etc.

Gradual Emergence.—A very great complication in the study of heredity, particularly again in man, is that at no time in the life of the individual does there exist, or is possible, a full and complete expression of his hereditary endowments. At all periods of life, from the very beginnings of the individual, some of his heredity has already emerged and produced its effects and these have been followed, obscured or even wholly superseded by others; while at the same time an indeterminate quantity of heredity is still dormant, still to be matured and then discharged. The more attention is paid to this subject the more it becomes evident that, as everything else in an organism, so heredity has what can only be termed its own life course, and that it must be viewed as an endowment gradually developing and emerging throughout the organism's existence, even to his death; all of which in marvelous regulation quantitatively, qualitatively, sequentially and chronologically.

As the age of the individual advances, one hereditary potentiality after another is discharged, weakens and fades out. The hair begins to gray or fall out, the sexual functions terminate, the teeth weaken and are lost, the strength diminishes, the eyes fade, resistance totters—until some disease cuts short the career, or until hereditary emergence dies out and the body dies with it. The last "breath" of heredity under normal conditions, would also be the last breath of the lungs, the last beat of the heart, the last flicker of consciousness.

These seem to be in a measure new realizations. They imply that the genes themselves have their life-course of progressive development and function, to which the rest of the organism conforms. Heredity is not at any time of life a reservoir of impounded ready-made influences that are gradually being discharged, but a flux of progressively developing active emanations that even more than organic evolution deserve the term *emergent*.

Location.—The next large problem concerning heredity is its location in the developing organism. In the inception the hereditary endowment must naturally have all been located in the genes and perhaps plasma of the egg and the sperm, but where is it lodged and from where does it work during the life of the individual? In other words what, outside of the germ cells, is the spatial location of the function of heredity in an organism, and particularly in man? Is it limited to the genes of the cells of the all-controling central nervous system, or is it generalized in the genes throughout the organism? And if generalized, as seems most probable, has it specialized with the different tissues and organs so that, for instance, the dermal cells, after their differentiation is finished, carry only genes that discharge dermal, the brain cells only genes that discharge brain heredity? These queries may at first seem odd, but they are not so on closer attention.

So far as known all the cells of the body receive the same chromosomes and the same genes. That this is so appears to be corroborated in various lower organisms where whole complex parts are regenerated, when lost, from partly like and partly unlike tissues. In man and in other higher organisms repair seems to be possible only by elements of the same tissue, which means a more advanced cell specialization. Such specialized cells are presumably capable of discharging only heredity of a particular kind—the epithelial cells the heredity of epithelial tissues, the nerve cells that of the nervous structures, etc., which agrees with the generality of the observable facts. According to this concept every separate tissue and organ of the human body would possess its own heredity emergences, the rest being in some way inhibited or obstructed.

That the germ cells have no influence on the rest of the cells of the body in these respects, is shown by the impossibility of such effects before the germ cells have reached maturity, or in advanced years where they ceased to be produced, or in cases where the spermatozoa or ova were killed by rays or disease, and in cases of spaying or emasculation. In the last

named instances certain systemic changes follow but they are due to the deprivation of the body of the secretions of the sex glands.

A great problem is the role in the workings of heredity of the central nervous system. The influence on the functions of the body of the cerebrospinal together with the sympathetic centers and ganglia, together with the aid given by the secretions of the ductless glands, seems absolute; and as the workings of heredity are a true function of the cells or genes, so it would appear this too must be controlled. Other conclusion seems impossible, unless the claim could be ventured that it is the central nervous system itself, after its formation, which embodies and discharges heredity. The evidence of successful grafts, and that of anencephalic monsters seems to oppose, the paralyzing and degenerative changes following certain brain or spinal cord injuries to favor such a view. These are as yet unexplored acres. Physiology and medicine know many connecting facts in these respects, but their true interpretation is difficult.

What may provisionally be concluded on the subject of localization of the functions of heredity is that, according to present indications, this localization is pansystemic, but specialized for each separate tissue and organ, and controlled in its discharge and workings by the nervous centers.

The subject seems further complicated by the relative masses of the different tissues in different individuals, under normal conditions. If every cell in a given tissue or organ carries a definite amount of hereditary potentialities, as would seem probable, then the resultant hereditary emanations ought to be proportional to the number of cells in such a tissue or organ. If this is true, then the totality of the emerging hereditary influences in a series of subjects could be expected to be biased in accordance with the defect or excess of given tissues in each individual under or over that taken as a standard. Thus conceivably even identical twins in one of whom one and in the second another system of tissues would accidentally or otherwise be developed to a

materially greater mass, ought to differ somehow in their hereditary expression. Perhaps the nervous control takes care of this; but perhaps also this touches the roots of "constitutional" differences in humans.

We are now dealing with matters which are largely outside of the possibilities of experimentation on lower animals, and practical approaches to which must be mainly observational and analytical. Such observations lead next to the appreciation that all the hereditary endowments of any creature, but man more especially, are far from equally fixed or equally potential.

Relative Fixity and Strength of Hereditary Endowments.— In the studies of human heredity it has long since become evident that the older the hereditary endowment chronologically, *i.e.* phylogenetically, the more fixed it is and the harder to alter or get rid of, and vice versa. The five fingers and toes, the greater length of the medius than that of each of the other fingers, the whole ground plan of the body and the skeleton, all the vital functions, all the instincts, are examples of the old and most fixed inheritances; while blondness, many of the special physical and physiognomic characteristics of the modern civilized man, and many of his higher mental attributes, are among the latest acquisitions and least stable. The point in all this is that in man, and probably in all other living beings, it is necessary to take cognizance, aside from the mendelian dominance of one factor over another due to the sexual differences in the strength of these factors, also of the dominance of greater fixedness and greater potentiality, regardless of sex. It is not improbable, even, that mendelian dominance may in general become explainable on these bases.

The dominance of old over more recent heredity is shown most palpably by the rapid changes to more ancestral forms in various characteristics of domesticated animals that have reverted to wild existence.

Latent Heredity.—A phenomenon observable now and then in human heredity is the revival, in some individual, of an ancient prehuman character that seemingly had already been

lost during human evolution. This applies to various physical, physiological and also mental features. As geological time went on and the human line evolved, various old hereditary endowments lost their importance, or were neutralized more or less, or covered, by later hereditary acquisitions, and as a result their manifestations weakened, or became submerged and dormant, finally in cases to vanish completely. But a large number remain, and the persistence of these weakened hereditary items is very striking, extending in instances to whole eras and tens of thousands of generations in duration. Their manifestations in man are the innumerable reminiscences of the past which, in instances, revive sufficiently to reproduce more or less an ancient structure and are then known as atavisms, such as for instance the supracondyloid process of the humerus, or the fourth molar; or they exist or revive during the embryonal life or in infancy, such as the external tail, or the running on all fours, and then become rudimentary or give place to manifestations of later heredity. Human infancy, as I have shown in the study of *Children Who Run on All Fours*,[1] is full of functional temporary revivals of this nature. It is evident that the heredity of such characters has not really been lost in the evolutionary course, but only repressed or weakened, and that in some individuals and under some conditions more or less of the old potentiality for the character is liberated or restored.

All atavisms or reversions under this view become thus really revivals and their occurrence collectively is an indication that besides his emergent heredity, or that which comes to be manifested in his life, every human carries amounts of heredity that in the course of time have become weakened, restrained or inhibited, but remain capable under favorable circumstances of more or less resuscitation.

Mendelism.—In plants and animals the workings of heredity follow in general the well-known mendelian laws, though there are numerous minor irregularities which so far have received insufficient attention, being over-shadowed by the

[1] McGraw-Hill Book Co., N. Y., 1931.

main phenomena. What the conditions are in the primates is as yet rather vague, the data being still meager. As to man, there exists already a vast amount of more or less directly relevant observations and discussions, yet not enough definitely to settle many and especially the main problems.

From what is known about heredity in man, it appears that its processes and manifestations are basically the same in him as in living beings in general; the mendelian laws are manifest also in the workings of heredity; but there are notable exceptions, and there come into play conditions which do not operate, or do so much less, on other creatures.

In many normal human characteristics and functions, such as the color of the skin, the physiognomy, the size and shape of the skull, the mental characteristics—the mendelian laws apparently do not apply, or apply in but a faint manner. In place of clearly defined dominance, recessiveness, and segregation in the second and future generations of a racial mixture, what shows mostly is more or less of blends, incapable for the future of full dissociation. In the color and form of the hair, especially in the color of the iris, in various mental phenomena, etc., there may be partial reversions to one or the other of the principal ancestors, but apparently never a complete reproduction of any of the ancestral forms. It would seem therefore that the male and female genes in man in a large measure blend or cooperate more intimately than they do in other organisms.

Crossed Inheritance.—An interesting peculiarity in the workings of human heredity is the popularly well-known fact that, with all its blends, the sons frequently "take" more, mentally, physically or both, after the mother, while the girls will resemble more the father. I am not aware of any scientific data on this subject, but everyone with experience has seen more or less palpable examples of such crossed inheritances. A point in this connection is that a greater resemblance to one parent in childhood, especially physically, may after puberty fade out or even change to that of the other; or that a resemblance to one parent, especially in

habits or mentally, may become more manifest after puberty
and even later in life, than it was earlier. This would seem
to indicate that the relative potentialities of the parental
genes do not always remain the same during the life of the
individual but that for a time those of one parent and then
those of the other may predominate.

Interferences.—A complication that affects the studies of
heredity is the complex of environmental or more properly
extra-gene circumstances that favor or repress the workings
of heredity, and particularly so in such a highly organized,
and through the extraordinary development of his brain
substanially altered, being as man. Heredity in no human
being can have untrammeled play, or at least not so in all
directions. From his very inception the emergence of his
heredity is affected more or less by nourishment, stimuli, and
repressives received through the mother; while after birth he
is acted upon by the quality and quantity of nourishment,
by bacterial hosts, by the totality of his environment. To
which are soon added all the rules and inhibitions of training
with education, and in time all the more powerful impulses
originating in the mentality of the individual himself. The
emergence of heredity, therefore, in the human being, is not
a fully free process but one beset by many stimulating or
checking influences, that cannot but have their results both
somatologically and functionally. This means that the
student of human heredity is in many respects confronted
by obscured or acquired results, which render his researches
much more difficult.

Individual alterations.—Hereditary potentialities are very
tenable and even if modifiable more or less in the individual,
they cannot be altered permanently by any ordinary means.
But they may be damaged or even destroyed by poisons,
particularly those of disease, by appropriate rays, and by
great shocks. And in the long run the genes and hence
heredity may evidently be altered regressively, in normal
ways, and even progressively by a multitude of agencies
acting in given families on a series of generations. These

alterations in heredity can only be conditioned by physical or chemical changes in the genes and whatever these connect with in the germ cells. How such gradual alterations in the genes or their auxilliaries are brought about is as yet uncertain. That such alterations become set and transmissible, is a proof they do become the property of the genes and germ cells, and these could only have thus effectively been reached, it would seem, either chemically or through nervous or other radiation. The corpuscular theory of Darwin which stipulated the germ cells to be affected by potential particles carried to them from all the different parts of the system by blood, has found no material support; but if not that then there would seem to remain only chemical effects, or nervous and other radiant impulses, of which in the case of progressive changes the latter would appear the most probable.

The gist of the matter is that, so far as man is concerned, lasting alterations in his individual hereditary endowments are possible; that many such alterations are of pathological nature; but that there are observable also changes in normal individual human heredities some of which, at least might prove progressive, if conditions for a long time were favorable.

GROUP MANIFESTATIONS

Hitherto both in the general studies of heredity and in this paper, attention had been centered on the conditions in individuals and their families; it is now timely to extend the scrutiny, and that particularly in man, to what may be termed group manifestations of heredity. By group manifestations are meant such workings of and especially changes in heredity as are manifested jointly by whole blood-related communities, tribes, nations, or races,—or that are even panhuman.

Such group manifestations are naturally but summations of individual changes, but they are generalized changes and can be fully shown only by the group.

The most common of such phenomena are group fecundity and mortality; group changes in pigmentation, stature, head

form, teeth, jaws, physiognomy; all the transmutations that lead either to lasting group weakenings or improvements, and organic evolution in general. A brief notice may here be taken of several such group phenomena.

Accretion.—Somatologically perhaps the simplest of these concerns the mass of the body. A progressive hereditary accretion is observable, for instance, in the stature of the older American families. The stature in these families has been slowly increasing for several generations, until the old Americans of today are the tallest larger human group in existence.[1] The process according to the latest measurements of the college students in various parts of this country appears to be still continuing, has extended to even the more recent American population, and has within recent years become observable also in Scandinavia, Holland, Japan and other parts of the world. Here are probably several influences at work, namely, a liberation of the hereditary stature-potentialities from repressions, and continued wholesome stimulation, with ample nutrition.

There are many examples of similar progressive accretions in the palaeontological history of various other organisms particularly in the size of the body, tusks, horns, brains, and other organs. Such changes, at first propitious and useful, beyond a certain degree may prove very disadvantageous and even detrimental.

Integration.—An important group manifestation of human heredity is integration. Wherever any segregate human group intermarries within itself for a prolonged number of generations, no matter how mixed such a group may have been to start with there manifests itself within it a progress towards the formation of a more homogeneous unit and type, in other words a progress towards somatic, functional and even intellectual integration. It is as a result of this phenomenon that the many existing nationalistic aggregates, though all of a very heterogeneous origin, have in the course of time developed approaches to national types which, if

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[1] See Hrdlička, A., *The Old Americans*, Baltimore. 1925 (Williams & Wilkins).

they could be kept from further material admixture from
outside, would in all probability proceed towards the forma-
tion of distinct human races or varieties.   Even in this coun-
try, among the older stock there are already distinguishable
approaches in that direction; and the still more interbred
Appalachian mountaineers show even more uniformity.[1]   The
basis of such integrations must be largely a blending of hered-
ity, but this is not the whole explanation.

   Restitution.—Among the most remarkable and important
phenomena connected with heredity, are that of the control
of the coördination and balance of the hereditary manifesta-
tions in any given organism, and that of restoration or
compensation when any part is damaged or lost.   Both of
these are the results of a definite function of the central ner-
vous system, but this function is so universal that it must be
among the most fundamental attributes of heredity.   Its
effects are regeneration and restoration of the blood, bone,
tissues of organs and brain machinery, after damage or dis-
order.   Where it fails there follow lack of repair or dishar-
monies of structure, function, mentality.   And this is not
merely an individual but also a group phenomenon.   It
means that when the harmful agencies have not caused a fatal
defect, everything tends gradually towards a compensation
and restitution.   In medicine this beneficial phenomenon has
long been known under the term *vis mediatrix naturæ*—the
nature's healing power.   Were it not for this, whole families
and perhaps even groups would have died out or would now
be dying from the effects of syphilis, tuberculosis, insanity,
and other serious maladies the predisposition to or the harm
of which are heritable.   What happens instead is that, while
the badly damaged individuals are eliminated, in the rest the
transmitted damages are gradually overcome and in the
course of time, with the help of more normal strains, the
family or group reach once more to or near the realm of
normalcy.

   Heredity and Human Agencies.—Various constituents of
human heredity may be fostered, or hindered, consciously

[1] See Hrdlička, A., *The Old Americans*, Baltimore, 1925 (Williams & Wilkins).

or unconsciously. Its emergence may be accelerated by
training, education, will, favorable conditions, by all the so-
called 'eugenic' agencies; it may be retarded or even neutral-
ized in a measure by unfavorable or 'dysgenic' conditions, by
the conscious building up of 'walls' of resistance, or through
compensation. The whole moral training of man is based
largely, if empirically, on these possibilities, and so is much
of medicine. Eugenics in this light might be defined as the
science of the promotion of normal heredity.

Higher Mental Phenomena.—The above does not yet
exhaust the peculiarities of the workings of human heredity.
The field of higher mental phenomena has barely been
touched. One of the most baffling manifestations in this
line, based unquestionably in some way on heredity, is the
origin from common stock of greatly talented individuals
and even of real geniuses and again the extinction of such
talents or geniuses in their progenies and communities. All
that can be surmised in this connection is that in the first
case there must have chanced rare and highly favorable gene
unions or relations, while in the progeny this is disturbed by
the introduction of less propitious gene-endowments through
the mate of the exceptional individual.

Evolution.—In view of the palæontological history of man
and of organic beings in general, this is the most conse-
quential of all the group phenomena connected with heredity.
It means a progressive development of whole parts or species
in lines of new adaptations or acquisitions, towards new parts
and species. The substance of the progress can only be
generalized changes in the hereditary endowments of a species
and consequently in its germinal cell genes, plasma and organ-
ization. There can be made no effort here at a discussion of
this vast subject. Suffice it to say that the hereditary
changes involved in evolution reveal some new phenomena,
which are, first, orthogenesis, or progression in a part or
organ in a given direction; and, second, a tendency towards
progression in the directions of greater complexity and greater
effectiveness. There are many complications in this through

natural selection and other factors, but what appears clear in
view of the facts is that the genes and whatever else is con-
cerned with heredity must be capable of very great differ-
entiation.

The Dying Out of Heredity.—As the individual organism
advances in age, all or nearly all of the important potentialities
of his hereditary endowments have been gradually discharged,
changed into kinetic influences and become used up or ma-
terialized, with less and less remaining to be given and done.
The effervescence of childhood and youth is followed by
relative stability, which slowly passes into the weakenings and
disharmonies of senility, and these progress until some vital
part of the system is no more able to proceed or resist suffi-
ciently and the individual reaches his death, the breakdown
of the worked-out machinery. The exhaustion of the chief
hereditary potentialities is inevitably followed by death of the
individual—a final evidence of the close relationship of life
and the charge of heredity.

Conclusion.—In conclusion of these few reflections on
human heredity, I can offer only the realization that the
problems of heredity in man differ in many respects from
those in other living forms, are infinitely complex, all-im-
portant, close to if not identical with life itself, and far as yet
from being adequately covered and understood. No defini-
tion of heredity, even if it could prove so faithful as to be
generally acceptable, is yet capable to offer an explanation of
the basic substance and workings of the phenomenon. Genes
help to locate the bearers of heredity in the cell and experi-
ments help to show the gross mechanism of heredity but
neither is capable of giving a full understanding of the process.
There must of necessity be some material determinants, be
they clusters of or single molecules, that carry or embody
heredity and will be able to cause certain results, chemical,
morphological, functional and even mental; but just how this
is done, how the potentiality is embodied, discharged and
becomes effective, is as yet wholly obscure. There is nothing
in chemistry or physics or dynamics that even suggests any

relation to such workings. We may say this is something "organic," but that is hiding behind a word that itself is no better understood. The emergence of heredity is tremendously well ordered, efficacious, lasting—how can its determinants be so small and yet evidently so highly organized and influential? The total ancestral heritage of man, reaches in some respects millions of years back, condensed to almost nothingness in the germ cells, yet with the power to induce the faithful reproduction of everything received, and that during the long life of the highly complex human individual. All this merely in appreciation that we are confronted here with problems that are as yet far from solved and even seem, for the present, beyond man's comprehension.

SOME FRAGMENTS OF THE OLDEST BEATTY PAPYRUS IN THE MICHIGAN COLLECTION

HENRY A. SANDERS

This lot consisted originally of eight small fragments (Mich. Inv. 5554) which were reduced to six by combining. The largest is about four inches square, the smallest two inches by one. They were purchased for the University by E. E. Peterson, Director of the Excavation at Kom Aushim, in 1930 and were sent to the University with other fragments and documents purchased that year. I saw them in the summer of 1930 and identified them as belonging to Deuteronomy. Also about that time word came that Mr. A. Chester Beatty of London had made a large purchase of Biblical papyri the previous spring, so there was immediately the suspicion that our small fragments came from the same discovery. On my return to Europe in September 1930 I took with me photographs of the eight fragments. Mr. Bell of the British Museum confirmed our surmise that the fragments belonged to the manuscript of Numbers and Deuteronomy of which Mr. Beatty had purchased a considerable portion. As that manuscript was in very fragmentary condition, it had been sent to Berlin to be mounted by Dr. Ibscher. There I saw it a few days later and the leaves to which our fragments belonged were determined. The photographs were left with the manuscript and later came into the hands of Sir Frederic Kenyon, who is engaged in publishing the Beatty Papyri. Thus far he has published only the New Testament fragments, but when he reaches the Numbers-Deuteronomy papyrus he has the permission of the University to include its fragments also. In the mean time I am exercising our right to prior publication.

This papyrus is certainly the oldest of the Beatty Collec-

tion.   Sir Frederic in Vol. I, p. 7 of *The Chester Beatty Biblical Papyri* has dated it in the second century A.D.   On p. 13 of my edition of the Epistles of Paul (University of Michigan Studies, Humanistic Series, Vol. XXXVIII, Ann Arbor, 1935) I have also dated it around the year A.D. 200, though I do not venture to affirm that it was from the second century. The difference is, however, not important.   The fragment was certainly from a time well before Origen and thus must have escaped the influence of his great Hexapla edition. Whether this manuscript also will have examples of accommodation to the original Hebrew such as were found in the papyri of the Minor Prophets and of Genesis published by me in 1928, can not be affirmed on the basis of these few fragments.   It is to be hoped that the larger Beatty fragments will be able to decide the matter.

Of the six fragments as at present united, the first three, one from Chapter 11 and two from Chapters 28–29, show that the text on the recto precedes that on the verso, while the last three, Chapters 30 to 32, reverse the order.   Below the text on fragment D there was found a tiny bit of papyrus firmly stuck on, having on the upper side the uncial H following remnants of an illegible letter, below which in semi-cursive]θεῖσα[.   The verso is blank.   This may be a bit of a marginal note on the bottom of the page which preceded this fragment in the manuscript, or it may be a foreign bit of papyrus.

The writing is a small delicate hand without shading of vertical strokes or the other ornamental additions usual in the third and fourth centuries.   In general, the forms of the letters accord well with a date in the late second century, though the prolonged middle stroke of ε, the enlarged ο and the use of ornamental line fillers are more prevalent later.

As this is the oldest manuscript of the Septuagint thus far discovered, the character of its text is most important.

In these small fragments we find evidence of over fifty variants.   In nineteen cases the papyrus is without support, of which nine are of some importance.   It seldom agrees with B

when that manuscript is supported by only a few minuscules. No manuscript agrees regularly with the papyrus. Of the uncials, G, which gives the Hexaplaric text, has the most agreements, ten, while all the others have either six or seven agreements except B, which has only three. Of the minuscules, x[1] stands the nearest with eleven agreements, c and u next with ten each, while b and w have nine each.

In my study of Θ, the Freer Deuteronomy and Joshua (University of Michigan Studies, Humanistic Series, Vol. VIII, Ann Arbor, 1917), I pointed out the remarkable agreement between Θ and minuscules 54 and 75 (Brooke and McLean, g and n) in Deuteronomy. This is confirmed by the comparison with our papyrus which agrees with Θ, g, and n exactly the same number of times each, six.

Of the minuscules not included in the Brooke-McLean edition, Nos. 108 and 118 of Holmes and Parsons are notable both for agreements and disagreements. When not in accord with the papyrus they generally agree with B. There are ten agreements of MS. 108 with the papyrus and eight of MS. 118. These manuscripts are also found supporting b and w and less often B.

The general interrelationship of the papyrus with the manuscripts just mentioned can be indicated by listing the more notable readings.

11. 17 $\overline{κς}$ υμιν: against Θ b g n w 108, 118 (ὑμῖν Κύριος).
    32 ποιειν for τοῦ ποιεῖν = G Θ b c g i * m n o u w x a₂ 108, 118, 128.
    ταυτα for αὐτοῦ = G (sub -) c x Sah; A y have μου.
28. 23 — $\dot{η}^2$ = F G N b d m n o p q t w x * b₂ 108, 118 Arm Eth Lat[r].
    24 τη γη for τῆς γῆς = A B F[a] G M Θ c l o t s u v y a₂ b₂ 85, 130 Lat[rz].
    28 Omit και before αορασια = B b w 108.
    Omit και after αορασια = b u w a₂ 108 Lat[z].
    35 σε υγι[αναι] for σε ιαθῆναι = b w; 108, 118 (υγιαναι σε).

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[1] Brooke and McLean numbers are used so far as given, supplemented from Holmes and Parsons.

29. 2 — τοὺς = A G M a h r y b₂.
31. 21 επι[λησθη]σεται: for ἐπιλησθῇ = Θ c d e g j l n p s t u v x z
          a₂ 16, 30, 46, 71, 73, 74, 76, 77, 85, 130.
     με εισαγα[γειν] for εἰσαγάγειν με = Θ b g l n b₂ 108.
32. 27 — πάντα = h 81; F Θ c g i x b₂ transpose.

Some of the above readings need a word of explanation.
The use of ταυτα for αὐτοῦ in 11. 32 has very weak support
and in G it is marked with an obelus. Therefore it seems it
was in Origen's Septuagint text and he marked it for deletion
because it did not appear in the Hebrew. Only two of Brooke
and McLean's manuscripts omit, k and o, but μου as well as
αὐτοῦ appears as a variant. All three of these variants prob-
ably antedate Origen; only the omission can be considered as
due to his influence.

The three agreements with the very small group in 28, 28
and 28, 35 suggest that there must be a closer relationship to
b, w, and 108 than the total count given above would suggest.
Probably all contain a goodly amount of pre-Origenic Egyp-
tian text, either somewhat corrected in each case or from
differing types.

The transposition in 31, 21 is characteristic of the same
type but there w as well as 118 has suffered change. In 11, 17
the transposition characteristic of this type does not appear
in the papyrus. There are two other cases where the mem-
bers of this group seem to unite on a variation which does not
appear in the papyrus. The evidence is too scanty for a
definite conclusion, but it seems to show that the papyrus is
related to the parent or to one of the parents of this group.
B has a similar relationship to this late group but it is less
close and there is no bond between the papyrus and B except
that both originated in Egypt.

The notable readings of the papyrus for which I have
found no support are the following:
11. 17 ην for ἧς.
28. 28 [παραπλη]ξαι for παραπληξίᾳ; probably due to the influ-
          ence of an iota adscript; cf. 28. 22, ωχραι for ὤχρᾳ,
          where the reason is obvious and where the abbre-

viation stroke over αι came from some attempted
correction.

34 Space indicates that σου was omitted.

29. 2 εκαλε for ἐκάλεσεν.

30. 16 πορευσεσθαι for πορευεσθαι.

31. 3 [κατακληρονο]μησαι for κατακληρονομήσεις.

29 [ημερ]ης for ἡμερῶν.

32. 27 + οτι after ταυτα.

The notable variants of B in the same passages which
are without support, are as follows:

28. 24 + ὁ θεός σου.

— ἐπί σε.

(σε²) + ἐν τάχει.

28. 29 (ὡς εἰ) + τις.

— σοι (after ἔσται).

41 — σοι (after ἔσονται).

65 (καρδίαν) + ἑτέραν.

32. 10 + γῇ (ἀνύδρῳ).

The text of B is quite as erratic as that of the papyrus and
there is never agreement between the two in these singular
readings. Only when b w 108 or 118 also agree are the
papyrus and B found in support of the same variant, and
either of the two older sources may vary from this type. If
we may judge from this small sample the most notable con-
tribution of this old papyrus manuscript will be to discredit
the text of the Vaticanus (B) which has so long been the
standard for the Greek Old Testament.

The Text of the Fragments

A recto

Deut. 11, 17–18

¹⁷και ου]κ ε[σται ο υετος και

η γ]η ου δ[ωσει τον καρ

πον αυτης και απολ[ε]ι

σθ]ε εν ταχει απο της

5 γης της αγαθης ην ε

δωκε κ̄ς̄ υμιν ¹⁸και

εμβαλειτε τα ρηματα
ταυτα εις την καρδιαν
ϋμων και εις την ψυ

A verso

Deut. 11, 31–32

-σαι την γη]ν ην [κ̅σ̅ ο θ̅σ̅
υμων διδ]ωσιν υμ[ιν
εν κληρω πασας τας
ημερας και κατοικη >
5   σετε εν αυτη ³²και φιλα
ξεσθε ποιειν παντα
τα τα προσταγματα
ταυτα και τας κρισεις

Line 7.   First τα crossed out by later hand.

B recto

Deut. 28, 22–25

²²ανεμ]οφθορι
α και τη] ωχρα̅ι̅ και κα-
ταδιω]ξονται σε εως
αν απ]ολεσητε ²³και ε
5   σται σ]οι ο ουρανος ο υ-
περ κ]εφαλης σου χαλ
κους] και η γη υποκα
τω σου] σιδηρα ²⁴δωη κ̅σ̅
τον υ]ετον τη γη σου κο
10   νιορτ]ον και χους εκ του
ουραν]ου καταβησεται
επι σ]ε εως αν εκτρει
ψη σε] και εως αν απολε
ση σε] ²⁵δωη σε κ̅σ̅ επι >
15   σκοπη]ν εναντιον των

Line 4.   τ corrected to σ man. 2; i.e. ἀπολέσῃ σε
Line 8.   α is by second hand; first hand illegible

28, 27–30

δυνασ]θαι σ[ε ιαθηναι
²⁷παταξ]αι σε κ̄σ̄ [παραπλη
ξαι αορασια ε[κστασει
διανοιας ²⁹και ε[ση ψη
5   λαφων μεση[μβριας
ως ει ψηλαφησ[αι ο τυ
φλος εν τω σκο[τει και
ουκ' ενειδωσει [τας ο
δους σου και εση [τοτε
10 αδικουμενος κ̣[αι δι
αρπαζομενος π̣[ασας
τας ημερας κα[ι ουκ ε
σται σοι ο βοηθω[ν ³⁰γυ
ναικα ληψη κ̣[αι ανηρ
15 ετερος εξει α[υτην οι
κιαν οικο[δομησεις
και ουκ [οικησεις εν αυ
τη α[μπελωνα φυτευσεις

Line 8. First ει crossed out and ο written above by later
hand.

B verso

Deut. 28, 32–35

. . . εις αυτ]α κα[ι ουκ
ισχυσει]η χειρ σ[ου ³³τα
εκφορ]ια της γης σου
και πα]ντας τους πο
5   νους] σου φαγετε ε
θνος] ο ουκ επιστα
σαι] κ̣αι εση αδικου
μεν]ος και τεθραυ
σμε]νος πασας τας η >
10 μερ]ας ³⁴και εση παρα
πληκτ]ος δια τα οραμα
τα τ]ων οφθαλμων
α βλ]εψη ³⁵παταξαι σε
κ̄σ̄ εν] ελκει πονηρω

15   επι τα γ]ονατα και ε
        πι τας κν]ημας ωστε
        μη δυνασθ]αι σε υγι
        αναι απο ιχν]ους

Line 5.   φαγετε, first hand; αι above last ε, second hand
Line 14. λ from first hand, but κ written first.

28, 38–41

        εξοισεις ε[ις το πεδιον
        και ολιγα εισο[ισεις ο
        τι κατεδεται α[υτα η α
        κρις ³⁹αμπελω[να φυ
5   τευσεις και κ[ατεργα
        και οινον ου π[ιεσαι
        ουδε ευφρανθ[ηση ε
        ξ αυτου οτι οτι κα[ταφα
        γεται αυτα ω σκ[ωληξ
10   ⁴⁰ελαιαι εσονται [σοι εν πα
        σι τοις οριοις σ[ου και ε
        λαιον ου χρειση [οτι εκ
        ρυησεται η ε[λαια σου
        ⁴¹υιους και θυγ[ατερας
15   γεννη[σει]ς [και ουκ ε
        σονται σ[οι απελευσον
        τ[αι

Line 8.   First οτι deleted by dots over each letter, same ink.
Line 9.   ω first hand; corrected ο second hand.

C recto
Deut. 28, 65–66

        ⁶⁵αλλα] και ε[ν τοις εθ
        νεσιν] εκεινοις ο[υκ
        ανα]παυσει σε ουδ ο[υ
        μ]η γενηται στασις τω
5   ιχ]νει του ποδος σου
        κ]αι δωσει σοι κ̅ς̅ εκει

κ]αρδιαν αθυμουσαν
. . ᵉκλειποντας οφθαλ
μ]ους και τηκομενη[ν
10   ψυ]χην ⁶⁶και εσται η ζω[η
σ]ου κρεμαμενη >
α]πεναντι των οφθαλ
μ]ων σου και φοβη >
θ]ηση ημερας και νυ
15   κ]τος [κ]αι ου πιστ[ευ
σε]ις τ[η ζ]ωη σου [

Line 8.   ε written above is from the second hand.   Either
και or κε probably stood in the lacuna below it.

C verso

Deut. 29, 1–2

ου]το[ι] οι λογ[οι της δια
θηκης ους [ενετειλα
το κ̅ς̅ τω μω[υ]ση [στη
σαι τοις υιοις ι̅σ̅[λ εν
5   γη μωαβ᾽ πλην [της
διαθηκης οις δ[ιε
θετο αυτοις εν χ[ωρηβ
²και εκαλε μωυση[ς
παντας υιους ι̅σ̅[λ και
10   ειπε προς αυτου[ς υ
μεις εορακατ[ε παν
τα οσα εποιησε[ν κ̅ς̅
εν γη αιγυπτω ε[νω
πιον υμων φα[ραω
κ]αι τοις θ[ερα]πο[υσιν

Line 6.   ης added above οις by the second hand.

D verso

Deut. 30, 10–11

. . . .]θεον σου
εξ ολης] της καρδιας σου

και εξ] ολης της ψυχης
σου] ¹¹οτι η εντολη αυ >
5   τη] ην εγω εντελλο
μαι] σοι σημερον ου
χ υ]περογκος εστιν

30, 16

θ[υ σου ας εγω εντελ]
λ[ομ]αι σοι σημερον
αγ[α]παν κ̄ν̄ τον θ̄ν̄
σου πορευσεσθαι εν
5   π[ασ]αις ταις οδοις
αυτου και φυλας

D recto
30, 19–20   [δε]

δωκ[α] προ προσ[ω]που
ϋμων την ευλ[ογ]ιαν
και την καταραν και
εκλεξαι την ζωη̄ ι
5   να ζης συ και το σπερ
μα σου ²⁰αγαπαν κ̄ν̄

31, 3–4

σου κα[ι κατακληρονο
μησαι αυτους κ[αι ιησους
ο προπορευομ[ενος
προ προσωπου [σου κα
5   θα ελαλησε κ̄ς̄ ⁴κ[αι ποι
ησει κ̄ς̄ αυτοις κα[θα ε
ποιησε σηων κα[ι ωγ

Line 2. μησαι; αι changed to ε by second hand.   ιησους
probably abbreviated.

E verso
Deut. 31, 21

μαρτυ]ρουσα ου γαρ επι
λησθη]σεται απο στο

ματος] του σπερματος
αυτων] εγω γαρ οιδα την
5   πονη]ριαν αυτων οσα
ποι]ουσιν ωδε σημε
ρον π]ρο του με εισαγα

31, 26
[νο]

μ[ου τουτου θησετε
αυ[το εκ πλαγιων της
κ[ιβωτου της διαθη
κ[ης κυ του θυ υμων
5   κ[αι εσται εκει εν σοι εις
μ[αρτυριον

Line 5.   From 2 to 5 letters to be omitted.

E recto
31, 29
κ]αι

συναντησεται υμ]ιν
τα κακα της ημερ]ης
οτι ποιησετε το π]ο
5   νηρον παροργισ]αι

32, 3–4

εκ]αλεσα [δοτε με
γαλωσυνην [τω θω η
μων : θς αλη[θινα
τα εργα αυτου κ[αι πα
5   σαι αι οδοι αυτου [κρισεις
θεος πιστος και [ουκ εστιν
αδικια δικαιος κ[αι οσιος
κς ⁵ημαρτοσα[ν

F verso
Deut. 32, 10–11

ε]ρημω ε[ν δι
ψε]ι καυματος [εν ανυ

δρ]ω εκυκλωσ[εν αυ
το]ν· και επαιδευ[σεν αυ
5　το]ν· και διεφυλα[ξεν αυ
τ]ον ως κορην [οφθα]λ
μο]υ ως αετος σκε

32, 15 or 16

τ[------

F recto

32, 22

　　　　]κα
τω καταφαγε]ται

32, 27–29

υψη]λη και ο[υχι κς εποι
ησεν τ]αυτα οτι εθν[ος
απολ]ωλεκος βουλ[ην
εστι]ν και ουκ εστι[ν
5　εν αυ]τοις επιστημ[η ου
κ εφρονησαν συν[ιεναι
ταυτα καταδεξα[σθω
σαν εις τον επε[οντα

OBITUARIES

WILLIAM HENRY WELCH

Doctor WILLIAM H. WELCH died in Baltimore on April 30, 1934, at the age of eighty-four years, and after a remarkable career in medicine extending over sixty years, of which fifty were spent at the Johns Hopkins University where, in succession, he was professor of pathology from 1884 to 1916, director of the School of Hygiene and Public Health from 1917 to 1926, and professor of the history of medicine from 1926 to 1931. Upon his final retirement from active professional duties he became professor emeritus in the Institute of the History of Medicine which is associated with the splendid library that bears his name.

Doctor Welch was descended from a family of doctors—his grandfather, father, and his father's four brothers all having been physicians. His father stands out notably among the others, not only as a leading and successful practitioner, but as a socially minded member of the community of Norfolk, Connecticut, which held him in the highest esteem. He served his state in its legislature, and his country in Congress, and after his death a memorial fountain was erected in his honor beside the house in which he lived and in which his even more gifted son was born. This house now carries a bronze tablet placed there on the occasion of the eightieth birthday of William H. Welch, as part of the international celebration of the event held in Washington, in which the President of the United States participated. The last mentioned occasion was unique in the history of a scientist, for not only were the addresses of the President and of Doctor Welch carried by radio throughout the world, but in many other cities in the United States, in England, France, and Germany, as well as in Peiping and Tokyo, coincident celebrations were held.

Doctor Welch was graduated from Yale College in 1870, and from the College of Physicians and Surgeons (now Columbia University), New York, in 1874. Eighteen months were spent as interne at Bellevue Hospital, partly before graduation in medicine. The two years from 1876 to 1878 were passed in Germany, working under such masters as Waldeyer in anatomy, Hoppe-Seyler in physiological chemistry, Ludwig in physiology, and von Recklinghausen and Cohnheim in pathology. The original purpose was to follow the clinics in internal medicine, with neurology as a special field of study. As laboratory training in the fundamental medical sciences was in this country all but absent from the medical curriculum of the period, Doctor Welch followed a natural bent in seeking this foundation in Germany. A strong impulse to this course came also from the experiences at Bellevue Hospital under Doctor Francis Delafield, whose devotion to human pathology was as unusual as his knowledge was profound. As the two years gradually came to a close, Doctor Welch's interests became more certainly centered on pathology as a career, although the outlook was sufficiently discouraging. The six years following the return from Germany were spent partly in private practice, which provided the necessary economic support, and partly as professor of pathology at the University and Bellevue Hospital Medical College, where the first real courses in that subject ever offered in America were given.

Doctor Welch's European reputation, as well as his success as a teacher and investigator in New York, brought his definitive opportunity when in 1884 he was called to the Johns Hopkins University as professor of pathology and as advisor to the president and trustees in the selection of a staff for the Johns Hopkins Hospital (then under construction) and the faculty of the associated medical school supposedly soon to be established. The immediate need felt by Doctor Welch was for the new bacteriology which, under the influence of the amazing discoveries appearing in rapid succession from the laboratory of Robert Koch, promised to transform the

science and art of medicine. Hence the next year was spent in Berlin in work with Koch and his pupils, so that on his return to Baltimore in 1885, Doctor Welch was in position to offer a combined course in pathology, which embraced morbid anatomy, bacteriology, and pathological physiology, or experimental medicine. No such comprehensive course of instruction and research had previously been undertaken even in Germany, and the remarkable success with which it was conducted by Doctor Welch was a tribute to his extraordinary learning and versatility, and his great gifts as a teacher.

Doctor Welch's career as teacher, investigator, and educator may be divided into three periods, of which the longest is that devoted to the pursuit of pathology, extending actually from the Bellevue interneship in 1875 to the retirement from the chair of pathology in Baltimore in 1916—approximately forty years. The Baltimore professorship itself covered thirty years, and this in turn can be divided into two parts: that from 1885 to 1900, in which Doctor Welch devoted his energies chiefly to the laboratory; and another from 1900 to 1916, during which heavy and unremitting demands were made on his time by other institutions seeking his aid in the struggle upwards toward improved curricula and provision for research, which the successful example of the Johns Hopkins Medical School had made imperative. Doctor Welch yielded graciously to these demands and accepted the sacrifice of his own dominant passion in the interests of the general and, as he believed, greater educational good. Undoubtedly, a major effect of his wider influence was the creation of careers for scientifically trained men, which in the next quarter of a century was to bring American medical education and research abreast of the highest European models.

A measure of Doctor Welch's activity as investigator in pathology may be found in a partial list of articles based on studies made in Europe and America during his more strictly laboratory years. They include such subjects as pulmonary oedema, hemorrhagic infarction, thrombosis and embolism,

glomerulo-nephritis, adaptation in pathological processes, hog cholera and swine plague, acute lobar pneumonia, diphtheria, wound infection, typhoid bacilli carriers, and *Bacillus aëro-genes capsulatus, nov. spec.*

The next fifteen years were given over in considerable part to the wider public service already alluded to. Doctor Welch became the apostle, as it were, of the newer medicine in its application to teaching and research; and his trusteeship on such boards as that of the Carnegie Institution of Washington, the International Health Board, and similar institutions, enabled him to extend his wisely constructive influence into the field of general science and public health. The extent and variety of these activities may be indicated by selected titles from his many public addresses, among which are: Advantages of the union of medical school and university; advancement of medical education; higher medical education and its need of endowment; the material needs of medical education; the benefits of the endowment of medical research; the position of natural science in education, medicine and the university; the medical curriculum; the relation of the hospital to medical education and research; the present position of medical education, its development and great needs for the future.

The second main period of Doctor Welch's career was devoted to the creation of the School of Hygiene and Public Health in Baltimore. For this there was no adequate model; he conceived the school as something commensurate with the important position which the public health held in the esteem of informed and forward-looking men. As he had long pondered the matter and it had been the subject of some of his impressive addresses, he set himself the task of outlining an institution in which instruction and research should be equally represented. Fortunately, this model was realized in practice; it became the standard toward which European countries strove when opportunity presented, as was presently the case, for the establishment of similar schools of their own.

A few titles will suffice to indicate the part which Doctor Welch played in arousing and guiding opinion in this country regarding the public health: Modes of infection; considerations concerning some external sources of infection in their bearing on preventive medicine; sanitation in relation to the poor; relation of laboratories to public health; duties of a hospital to public health; child welfare; the significance of the great frequency of tuberculous infection in early life in the prevention of disease, and what may be expected from more effective application of preventive measures against tuberculosis. Another activity which brough large rewards was the part that Doctor Welch played in presiding at and attending congresses on hygiene at home and abroad, and in lending the weight of his name and great prestige to the public health movement.

We now come to the concluding period of Doctor Welch's rich and varied life. He retired from the directorship of the School of Hygiene and Public Health in 1926, at the age of seventy-six. But this gesture, like that of his retirement from the chair of pathology ten years earlier, was one of form only; it did not mean release from academic responsibilities, but rather the assumption of new duties. The new undertaking was one which appealed strongly to Doctor Welch's intellectual predilection and fell in with convictions which he had long held, namely that "the study of the history of medicine, notwithstanding its interest and value, is a study much neglected." The opportunity arose to put into effect this belief, and none other than Doctor Welch was available to assume the task. As a memorial to Doctor Welch's extraordinary services as a pioneer and innovator in medical education and research, a magnificent medical library was about to be erected and endowed, and the Institute of the History of Medicine, which he had hoped might some day come into existence, was now to be incorporated into the library bearing his name—its proper and most favorable home.

A digression is justified at this point. Doctor Welch's

compelling impulses toward scientific medicine revealed themselves early in his career. He had no more than graduated from Yale and entered the medical college than he left the latter, to return to New Haven for a year of advanced study in chemistry. This strong love for the fundamentals of knowledge was no passing fancy, it displayed itself again in Germany, when Doctor Welch sacrificed the clinic for the laboratory, through which he acquired the wide training and knowledge that were to enable him to lecture with a rare fascination and with equal facility on histology, pathology, bacteriology, and physiology, and to conduct and inspire research in all these branches. The encyclopedic breadth of his mind carried him also into literature, history, and the arts; and those who were so fortunate as to become his companions and friends found his geniality of person, charm of manner, and conversational gifts irresistible. Thus the history of medicine, which in reality for him was the history of science and civilization, was an absorbing avocation from his early manhood. To have had the opportunity at the close of an eventful life of generous length to add to his achievements the founding of the Institute of the History of Medicine was one of those fitting rewards that come oftener in romance than in reality.

But was not Doctor Welch's life one long intellectual and spiritual romance? To find a counterpart, we are driven back to the Renaissance era, and the comparison of Doctor Welch's versatile gifts with those of Leonardo da Vinci is not merely a fanciful idea. Had Leonardo been born into the nineteenth century, he might well have been a scientist; and had Doctor Welch been born into the fifteenth, he would by the same tokens have chosen the arts and literature in which to nourish his omnivorous mind.

We may conclude this brief sketch of Doctor Welch's career with selected titles of addresses which illustrate his interest in scientific, historical subjects: The evolution of modern scientific laboratories; the influence of anesthesia upon medical science; some of the conditions which have influenced the development of American medicine, especially during the

past century; the interdependence of medicine and other
sciences of nature; Rudolph Virchow, pathologist; works and
portraits to illustrate epochs in the history of medicine; the
times of Vesalius; contributions of Vesalius other than
anatomical; two physician-economists, Sir William Petty,
1623–1687, and Francois Quesney, 1694–1774; the develop-
ment of English medicine as represented in a collection of
medical portraits; the influence of English medicine upon
American medicine in its formative period; William Wood
Gerhard, and the differentiation of typhus and typhoid fevers;
the fiftieth anniversary of the discovery of the tubercle
bacillus; and the history of pathology.

SIMON FLEXNER

JAMES CORNELIUS WILSON

THE subject of this memoir was the eldest son of Dr.
Ellwood Wilson, and his wife Hannah Paul (Shallcross)
Wilson. He was born in Philadelphia, March 25, 1847. His
early education was acquired at the Friends' Central School
and a small private school conducted by the Reverend Dr.
Malin. Later he went to Phillips Exeter Academy, and,
thence, to Princeton College, where he graduated A.B. in
1867. He then began the study of medicine at Jefferson
Medical College from which he received his M.D. in 1869,
and in the following year (1870) got his M.A. from Princeton.
After serving as resident physician in the Will's Eye Hospital
and the Pennsylvania Hospital, he went abroad for further
study in Dresden and Vienna. Upon his return to Phila-
delphia, in 1873, he entered private practice and from the
outset engaged in teaching at his medical alma mater and in
hospital work. He was chief clinical assistant at Jefferson
to Dr. Jacob M. Da Costa, and in 1891 was elected professor
of medicine and clinical medicine in Jefferson Medical College,
which position he held until 1911, when he retired with the
title of professor emeritus. In 1889 he was elected physician
to the German (now the Lankenau) Hospital, becoming

physician-in-chief in 1897, and retiring as emeritus chief of the medical department in 1924. In 1895 he was elected physician to the Pennsylvania Hospital from which position he resigned in 1911.

In addition to these positions Dr. Wilson was consulting physician to many other hospitals and medical institutions. He was a frequent contributor to current medical literature and the author of a number of authoritative medical books, among which should be mentioned, "Summer and Its Diseases" (1879), "A Treatise on Continued Fevers" (1881), "Manual of Fever Nursing" (1887)." A Handbook of Medical Diagnosis" (1909). The last two went through a number of editions. In 1896 he edited a composite work, the "American Text-Book of Applied Therapeutics." The esteem in which Dr. Wilson was held by his professional colleagues is witnessed by the following list of societies of which he was elected president at one time or another:

The Philadelphia Pathological Society (1885–1886)
The Philadelphia County Medical Society (1895–1896)
American Academy of Medicine (1897)
Association of American Physicians (1902)
American Climatological Association (1904)
American Therapeutic Society (1909)
College of Physicians of Philadelphia (1913–1916)
The Medical Library Association (1913)

He was elected a member of the American Philosophical Society in 1885.

The above details serve to illustrate the professional standing of Dr. Wilson. His wide experience, keen powers of observation and accuracy of judgment made his services as a consultant invaluable. Aside from his professional attainments he was a man of much culture, a great reader and deep thinker. His kindly disposition rendered him greatly beloved. To younger physicians he was always friendly and helpful.

For some years before his death Dr. Wilson's health had been greatly impaired and he had retired from all professional

labors. He died on October 28, 1934, in his eighty-eighth year.

FRANCIS R. PACKARD

THEOBALD SMITH

IN THE death of Dr. Theobald Smith on December 10, 1934 the American Philosophical Society has lost one of its most distinguished members. Dr. Smith was born at Albany, New York, on July 31, 1859. He was graduated from Cornell University in 1881 where his associations with Professors Gage and Wilder gave him a life-long interest in general biological problems. He received the degree of M.D. from the Albany Medical School in 1883, and from 1884 to 1895 he was Assistant, and then Chief of the Division of Animal Pathology, Bureau of Animal Industry, Washington, D. C. From 1886 to 1895 he was Lecturer and then Professor of Bacteriology in Columbia, now George Washington University, and from 1895 to 1914 was Professor of Comparative Pathology in Harvard University. In 1911-'12 he was Exchange Professor from Harvard University to the University of Berlin. He was also Director of the Antitoxine and vaccine Laboratory and Pathologist of the State Board of Health of Massachusetts from 1895 to 1914.

He was a member of the Board of Trustees of the Carnegie Institution of Washington and a Scientific Director of the Rockefeller Institute for Medical Research from its beginning in 1901, acting as Vice-President of the Board from 1924 to 1933 and succeeding the late Dr. William H. Welch as President in October 1933. In 1915 he organized the Department of Animal Pathology of the Rockefeller Institute at Princeton, New Jersey and served as its Director until his retirement in 1929.

Dr. Smith's researches on parasitism and disease were very extensive and of the most far-reaching importance; only a few of these can be mentioned here. With Dr. Salmon he demonstrated for the first time that killed cultures of bacteria

may produce immunity; this is the principle now used in
protective vaccination against typhoid, paratyphoid and
cholera. While in the Bureau of Animal Industry in Wash-
ington he demonstrated between 1888 and 1893 that ticks
were the means of transmission of Texas cattle fever. This
was the first proof ever given that insects may transmit
disease germs and it opened the way to the discovery by
others of the method of transmission of malaria, yellow
fever, African sleeping sickness, etc. In 1896–'98 he proved
that the bovine type of tubercle bacillus differed from the
human type and this has played an important part in the
present campaign against tuberculosis. He first observed in
1904 cases of serum sickness and death in guinea pigs that had
received a second injection of horse serum, and this hyper-
sensitivity, which is akin to certain forms of asthma, hay
fever, etc. in man, was at first known as the "Theobald
Smith phenomenon." He demonstrated in guinea pigs the
immunizing action of balanced or neutral mixtures of diptheria
toxine-antitoxine, and this method is now in general use as a
preventive of human diphtheria. In addition to these and
other discoveries bearing directly upon the causes and control
of human diseases, Dr. Smith made many other studies on
diseases peculiar to domestic animals, which for lack of time
cannot be enumerated here. Fortunately he had published
only a few months before his death his Vanuxem Lectures
for 1933 on "Parasitism and Disease," in which volume he
summarized much of this work, and in which he emphasized
especially the biological interrelationships of parasite and
host. Indeed it may be said that it was his broad biological
outlook and especially his confidence in the principle of
organic adaptation between parasite and host that guided
him in all his studies.

His really epoch-making discoveries brought him world-
wide recognition and honors. He was a member of more
than a score of the leading scientific societies of America and
Europe, including the National Academy of Sciences of the
United States, the Royal Society of London, the Royal

Academy of Denmark, the Academy of Sciences of Paris, etc. He had been awarded by universities and scientific societies in this country and abroad eleven medals and twelve honorary degrees.

EDWIN G. CONKLIN

MICHAEL IDVORSKY PUPIN

THE well-known scientist, inventor, and philosopher, Michael Idvorsky Pupin, was born, on October 4, 1858, in a little Serbian village, near Belgrade, called Idvor, with which his middle name was linked. His parents were illiterate peasant farmers, who were hard working, frugal, and respected. Michael learned to read and write at the village school of Idvor. He inherited a strong physique and a propensity for persevering labor. He evinced mental ability and marked ambitions.

His parents sent him to seek better schooling; first, to the little town of Panchevo, and, later, to the city of Prague. Here he witnessed the oppression of the Bohemian Slavs, which made him aspire for greater freedom in North America. With difficulty, he procured passage money for a steerage berth in a steamer from Trieste to New York. He landed in New York at fifteen years of age, an impecunious immigrant, with very little knowledge of English. Soon he became a farm hand on a Delaware plantation. A member of the farmer's family helped him to study the American language and history.

After a year's experience in farming, Pupin went back to New York City in search of better opportunities for self-improvement. He arrived there in the summer of 1874 to find the city in the throes of depression with thousands of men on the streets seeking employment. Young Pupin joined in the search. With courage and cheerfulness, he managed to sustain a precarious livelihood on odd jobs, garnered at random, but the winter of 1874–5 was to him a bitter one.

Pupin finally succeeded in securing steady employment in

a New York factory. He made friends of two fellow workers, who persuaded him to study for college. With their aid, he studied Greek and Latin in his spare time. He also attended evening classes at the Cooper Union Institute. By the time he was 21 years old, he passed the entrance examinations of Columbia College with honors. This shows what sometimes can be accomplished in self-education by great effort and determination.

At Columbia, Pupin took honors in Greek, Physics, and Mathematics. In his first year, he was undecided on the choice of a career, but studies in physics, under the direction of Professor Ogden Rood, a fascinating lecturer, determined his selection of a scientific vocation. It is by no means rare to find a successful life path that has been opened to a college student under a teacher's torch.

On receiving his A.B. diploma, Pupin was offered a scholarship for three years graduate study at Columbia, but he decided to pursue graduate studies in physics abroad. He went to Cambridge, England, in June 1883, and arranged to enter one of the colleges there on the opening of the fall term. He then went to revisit his family at Idvor, which he had not seen since 1872.

At Cambridge, Pupin studied mathematical physics for two years. Professor Routh, the well-known writer on dynamics, was his tutor. In all his subsequent work, Pupin showed the benefit derived from a thorough grounding in dynamical methods.

Desirous of perfecting himself in physical laboratory procedure, Pupin went to Berlin, in 1885, as the first John Tyndall Fellow from Columbia University to study under von Helmholtz and Kirchhoff. He took his Ph.D. degree at the University of Berlin, in 1889.

Returning to America, in the same year, Pupin joined the teaching staff of his alma mater, Columbia University, in the departments of mathematical physics and electrical engineering. He was connected with the Columbia faculty for the remainder of his life. He had a forceful and dominating

personality which held the close attention of his students. He liked to illustrate a methematical argument with a simple physical demonstration. He discovered the now well-known phenomenon of secondary X-radiation, and was probably the first man, in this country, to demonstrate Röntgen's discovery of X-rays, when first announced.

Pupin engaged in mathematical investigations on the vibration of elastic strings loaded at successive intervals with uniform lumps of matter, and obtained the solution of this problem in 1895. It led him later to the solution of a co-related electrical problem—the propagation of alternating electric currents over a uniform conductor, containing lumps of inductance, i.e. inductance coils inserted in the conductor at regular intervals. The solution showed that a telephone circuit might be greatly improved by inserting inductance coils at specified distances. Heaviside, in England, had previously predicted that improvement of this kind could be obtained by the insertion of inductance, but he had left the sizes and distances of such coils open to experimental trial, without the specification of limits by calculation. The Pupin rule was found to give successful results, and was adopted by the telephone industry, both in this country and abroad. The success of "pupinised telephone lines" brought to Pupin considerable scientific and financial recognition. He received honorary degrees from Columbia, Johns Hopkins, Princeton and fifteen other Universities. He also was awarded the Hebert Prize from the French Academy and medals from the Radio and Franklin Institutes, in addition to other honors.

Pupin was famous not only as a scientist and inventor, but also as a writer. His autobiography, published in 1923, "From Immigrant to Inventor," enjoyed a wide circulation. It narrates in simple, but appealing style, the story of the author's early struggles against adverse fate. Through the narrative runs a strong current of faith and philosophy. Four years later, he published a second very popular book, "The New Reformation," which is virtually an exposition of his philosophy as a scientist.

Pupin served as a representative of Serbia at the Paris Peace Conference of 1919. He was instrumental in securing extended boundaries and privileges for the then new country of Yugoslavia.

In 1888, he married Sarah Kathrine Jackson of New York, in London, who predeceased him.

In the later years of his life, Pupin enjoyed some relaxation by aiding in various philanthropic projects. In particular, he sought to help his native country. He established a community house at Idvor. He also gave a foundation for the Royal Serbian Academy, at Belgrade, in honor of his mother, Olympiada, to whose memory he was devotedly attached. Moreover, he showed his veneration for the influence of monasteries, in Serbia, by assigning a fund for the restoration of some that had suffered decay. His faith has been revealed by his books, which express the hope of a future blending of scientific and spiritual truth.

During the last ten years of his life, Professor Pupin suffered from a slowly spreading paralysis of the lower limbs, which much interfered with his movements and locomotion; but it never affected the activity or serenity of his mind.

His life was an intrepid dauntless venture in overcoming obstacles. He personified a steady ascent from physical to intellectual, and finally to spiritual strength. He died, full of honors, on March 12, 1935, in the 77th year of his life.

Columbia University, since his death, has named its recently erected physics building the "Pupin Physics Laboratory," as a memorial to his life work in that department.

ARTHUR E. KENNELLY

CYTO-TAXONOMIC STUDIES ON CERTAIN OENOTHERAS FROM CALIFORNIA [1]

RALPH E. CLELAND

(Read April 19, 1934)

INTRODUCTION

THERE are two methods by which one may study the process of species formation with some directness. One is the method of experimental taxonomy, which attempts to observe directly the response or lack of response of living organisms to varying conditions of the environment, and to follow the vicissitudes of variants, whether genetically or experimentally produced, as they appear in the field,—to witness, in short, and to explain so far as possible, the actual process of modification as it is going on at the present time. The other is the phylogenetic method, which attempts to trace the paths by which present races have sprung in the past from a common ancestry, and to estimate, on the basis of the information thus gained, the degree of relationship existing between given forms. For various reasons, *Oenothera* seems to furnish unusually favorable material for the application of both of these methods to the solution of the problem of the origin of species.

Ideally, either of these two methods calls for the study of material which is actively evolving at the present time, or which has been in such a state in the recent past. One reason why *Oenothera* is such favorable material for evolutionary studies is that it gives evidence of being at the present time in the throes of active evolutionary development. It is a large genus, and includes a welter of forms which often do not possess the clearly demarcated characters of old and well

During the course of this investigation, assistance has been received from the following sources: National Research Council, Committee on Grants-in-Aid; Joseph Henry Fund, National Academy of Sciences; American Academy of Arts and Sciences; Penrose Fund of the American Philosophical Society. Technical assistance has been rendered by Messrs. Wm. H. Brittingham and B. L. Hammond.

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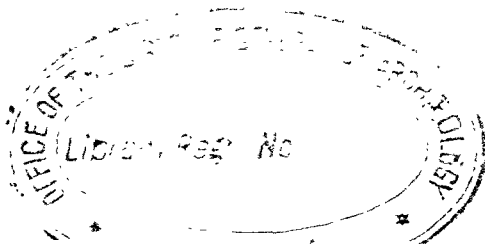
established species, but seem in many cases to merge more or less gradually into one another. Furthermore, extensive cyto-genetic studies have shown that genetical modifications such as gene mutations and chromosome alterations occur with considerable, even with exceptional, frequency; and in addition, it seems clear that hybridization is of widespread occurrence in the genus. Consequently, it would seem that *Oenothera* affords a good opportunity for the study of species in the making—for tracing lines of phylogenetic ascent, and for determining the relative importance of various factors, environmental and genetical, in species formation.

In the second place, *Oenothera* has certain practical advantages as material for evolutionary study, quite apart from the intrinsic interest of the phenomena which it displays.—at least this is true of the sub-genus *Onagra*, which is the only section of the genus which has been studied genetically and cytologically. For one thing, the various races cross easily with one another, yielding fertile hybrids. Furthermore, much intensive genetical and cytological work has already been done on *Onagra*, which has yielded valuable material bearing upon evolutionary problems. One feature in particular, however, bids fair to exceed all others in phylogenetic significance, namely, the presence of a type of correlation between chromosome behavior and genetical affinity which seems to constitute an important and unique tool for the study of species affinities in the group.

This correlation came to light as a by-product of the genetical work of Renner and his followers, and the independent cytological work of the writer. The extensive genetical analyses of Renner led him to certain conclusions (Hoeppener and Renner 1929) regarding the interrelationships of the various genoms or "complexes" which in *Onagra* are so characteristically passed on from generation to generation intact. The writer, who had previously studied the chromosome configurations in many combinations of these complexes, at once noticed a curious parallelism between the conclusions of Renner and his own cytological

findings. He drew attention (1931) to the fact that com-
plexes, which, according to Renner, are relatively similar
genetically, have relatively similar arrangements of the end
segments of their chromosomes, and consequently give mostly
or entirely paired chromosomes, when combined with each
other; on the other hand, complexes which Renner found to
be relatively dissimilar genetically have relatively dissimilar
segmental arrangements, and hence give large circles with
each other. It was evident that, if this correlation were
found to apply, not only to the complexes studied by Renner,
but to complexes of *Onagra* in general, then the number of
chromosomes which are paired or unpaired in a given complex-
combination, and the size of circles, would become a rough
measure of the genetic affinity between these complexes;
and hence the arrangements of chromosomes in diakinesis,
whether into circles or pairs, would become a valuable tax-
onomic character, to be considered along with phenotypic
differences in determining affinities between the various races
of *Onagra*.

There is, as a matter of fact, strong reason for believing
that such a correlation is really of widespread occurrence. In
the first place, such an assumption is *a priori* most reasonable.
If segmental interchanges which result in viable strains are
rare in occurrence (and the stability of chromosome configura-
tions in many strains, as shown by repeated examination of
their chromosomes, is evidence that even in *Onagra* such
interchanges are rare), then it is reasonable to suppose that
there will have been time between successive successful
interchanges for genic modifications to have occurred, so
that divergent complexes or genoms which have arisen from
a common source will show a degree of divergence, not only
genetical but also cytological, which will be roughly propor-
tional to the length of time since they began to diverge.[2]

[2] This is assuming that the so-called gene mutations are actually in the nature of
genic modifications. Should it turn out that many or most mutations are the result of
alterations in the position of genes, as is now being suggested (Muller, Prokofyeva and
Raffel, 1935), it would then be logical to assume that the very phenomenon of inter-
change itself would result in genetic alterations, in which case the correlation between
relative similarity of segmental arrangement and genetic similarity should be very close
indeed.

The longer that genoms from a common source have deviated,
the more segmental interchanges will have occurred, and the
more unlike will their segmental arrangements therefore
have become; at the same time, the more gene mutations will
probably have occurred, and the more unlike will the com-
plexes have become from the standpoint of genetical make-up.
Thus, we would expect that the chromosome configuration
produced by 2 complexes, when these are brought into union,
would give us in most cases a rough idea as to the genetical
similarity between these complexes, and hence as to their
phylogenetic position.

It should be pointed out, however, that the presence of
paired chromosomes or of small circles is undoubtedly a more
accurate measure of degree of relationship, and therefore of
greater phylogenetic significance, than is the presence of large
circles.   When we find a large number of pairs, or small
circles, the chances are strong that the complexes involved
differ by the minimum number of interchanges necessary to
produce this configuration; but when we find a circle of 14
(in *Oenothera, 2n* = 14), we cannot be sure how distant is the
relationship between the complexes involved, for, while a
circle of 14 can be produced by as few as 6 interchanges, it
must be remembered that even the most distantly related
complexes cannot show a more extreme cytological diver-
gence than that represented by a circle of 14.   It is very un-
likely, therefore, that a given complex-combination, with a
circle of 14, picked at random from the wild, will be composed
of complexes differing by only the minimum number of inter-
changes necessary to produce this configuration, whereas it is
extremely likely that such a complex-combination, with 7
pairs, or a circle of 4, for instance, will be composed of com-
plexes which differ by the minimum number of interchanges.

This conclusion is borne out by another consideration,
which also constitutes a second reason for suggesting that a
correlation between chromosome configuration and genetical
make-up must be of widespread occurrence in nature.   Seg-
mental interchanges, occurring at random, are much more

likely to result in complexes with divergent segmental arrangements, than in those with similar arrangements. Thus, if we shuffle the 14 ends of 7 chromosomes, and combine them with the shuffled ends of another set of 7 chromosomes, like ends being united, there will be but one chance in 54,016 that the 2 sets of 7 chromosomes will have identical arrangements of ends, thus producing 7 pairs; and there will be only 21 chances in 54,016 that these sets will produce a circle of 4, and 5 pairs. On the other hand, there will be 13,440 chances in 54,016 that they will produce a circle of 12, and 23,040 (or almost 1 chance in 2) that they will form a circle of 14 (see Cleland and Blakeslee, 1931, table 1, p. 182). It is probable, therefore, that the successive occurrence of interchanges in the wild will in general conduce to the production of complexes, which, when crossed with one another, will produce large circles, rather than paired chromosomes.

Since, therefore, the chances of the appearance of large circles are so great, it is clear that their presence in any given instance is of relatively little significance from the standpoint of phylogeny; all one can say is that the complexes involved are not closely related—but how distantly related they may be one cannot say. On the other hand, since the probability of the chance occurrence of similar segmental arrangements in unrelated complexes is so small, the most reasonable assumption, in any case where a large number of paired chromosomes is present, is that the complexes cooperating to produce them owe their similarity in segmental arrangement to the fact that they have never diverged very far from a common ancestral condition, that they are therefore closely related, and have probably had a relatively recent common origin. This argument is admittedly based upon the supposition that a given end can exchange, with more or less equal facility, with any other end, an unproved hypothesis. It should be possible, however, to determine whether this hypothesis is well founded or not by an extensive analysis of segmental arrangements as they exist in nature, a piece of investigation which is already well under way. At present, we may as-

sume as a working hypothesis, therefore, (a) that the presence of large numbers of *paired chromosomes* in a given complex-combination is, in general, evidence of close relationship between the complexes involved; and (b) that this correlation between chromosome configuration and genetical relationship furnishes us with a unique and valuable tool for use in arriving at an approximate understanding of the relationships between complexes, and hence between species.

With a view to testing the possibilities of this tool, the work to be reported in this paper was begun some 4 years ago, utilizing as material a group of *Onagras* from California. It was thought that the use of segmental arrangement as a phylogenetic tool would probably result in the relatively easy acquisition of a general understanding of species rela-tionships in *Onagra;* with this as a background, it would then be possible to study critically the rôles which various factors have played in species-formation. For instance, 2 genoms with identical segmental arrangement, and in contiguous areas, might be found to differ markedly in genetic composi-tion. If this situation were found to be prevalent, it would be an indication that gene mutations have been of importance in the formation of distinct races. Again, a certain genom might be found to be associated in one case with one genom, forming a given species, and in another case with another genom, forming an entirely different species (such cases are known); or distinct, but geographically overlapping races might be found to have contributed each a genom to a permanent and successful hybrid, forming a typical complex-heterozygote. The relative frequency of such cases would indicate the relative importance of natural hybridization in species formation. Thus, a knowledge of the segmental arrangements of the various species and their hybrids, to-gether with their geographical ranges, should prove an invaluable background and tool for the proper understanding, not only of the actual lines of evolution taken by *Onagra*, but also of the relative importance of mutation, segmental inter-change and hybridization in the origin of species.

With these possibilities in mind, a study of California forms was undertaken. Material was derived from seed obtained through the kindness of the late Dr. H. M. Hall, Dr. A. H. Sturtevant, and Dr. D. A. Johansen. This seed was collected in various localities, ranging from the vicinity of Pasadena to San Francisco, and from the sea beaches to the high Sierras. From these sources, 9 more or less distinct strains have been established, to which must be added *franciscana* and the *hookeri* of de Vries.[3] Detailed descriptions of these races will be found below.

These strains have been studied from 4 main points of view: (1) To what extent do these races, all of which have been known tentatively as *hookeri*, display under uniform garden conditions phenotypic differences, and hence give evidence of an actual genetic basis for the existence of distinct geographical races?[4] (2) How do they compare in cytogenetic behavior with other species? Do they contain lethals? Are they highly heterozygous, or relatively homozygous? If heterozygous, do they show evidence of the linkage of most or all of the heterozygous genes into a single super-linkage group, such as characterizes forms from other regions? What kinds of chromosome configurations do they have? (3) Judging from the chromosome configurations of their hybrids, as well as from phenotypic characters, how are they related phylogenetically to each other, and to species from other regions? (4) What are the segmental arrangements of their genoms? The answers to these questions should afford a better background for the evaluation of the relative importance of the various evolutionary factors.

Data with respect to these strains and their hybrids will now be presented, after which the data will be discussed, and conclusions drawn.

[3] Certain additional strains have recently been made available to the writer by Dr. P. A. Munz, which have yet to be analyzed.

[4] Owing to a lack of field knowledge, it is impossible at the present writing to compare differences between strains as found in the garden with differences as found in the field. It is hoped, however, that such a comparison will be possible in the near future, as a result of garden and field studies now being made by Dr. Munz.

DESCRIPTION

The number of hybrids examined for the first time in connection with this study is so large that it will be impossible to characterize each in detail. While wild races will be described in full, therefore, hybrids will be characterized in the briefest possible manner.

A. *Races from California*

In the present paper, no attempt will be made to define the taxonomic position of any of the races described. They will instead be designated by nicknames. This decision is made for 2 reasons: (1) The making or unmaking of species is justified only after the fullest and most adequate field knowledge of a group, a knowledge which the author does not possess; (2) a taxonomic revision of the sub-genus *Onagra*, based upon extensive field work, is now being made by the foremost authority on the taxonomy of *Oenothera*, Dr. P. A. Munz. Upon the completion of Dr. Munz's revision, the races herein treated can be assigned to their proper species.

1. "DALTON"

Pedigree.—This strain is derived from open pollinated seed collected by Dr. A. H. Sturtevant from a single wild plant in Dalton Canyon, near Glendora, Cal., in March, 1929. A selfed line has been maintained by the writer, with cultures in 1930, 1931, 1933 and 1934. The 1930 family consisted of but 5 plants, owing to the seed having been largely crushed in transit. These 5 plants showed variation in the size, breadth and flatness of their leaves, in other respects being quite uniform. Only 2 plants bloomed, a narrow-leaved type being chosen to carry on the line. Subsequent generations have been uniform, and have possessed the characteristics of the 1930 parent.

Characterization.—*Seeds* smallish, darkish brown. Seed germination (1931) 100 per cent, (1933, seed 2 years old) 25 per cent, (1934) 93 per cent. *Habit.* Plants 50–60 cm. high at Baltimore; central shoots absent, rosette branches spreading widely when heavily branched, or more erect when less branched; often much branched. *Leaves* deep greyish-green, narrow (*e.g.*, typical rosette leaf 23 x 3 cm.), except in some first generation plants; lower leaves somewhat crinkly and wavy at base in some first generation plants,

in later generations flat; marginal hairs erect (ee), marginal glands green, margins slightly reddened in young leaves, midribs white, red flecks absent. *Stems* dull red below, green above, reddened at tips, with both long and short pubescence; red papillae numerous and large. *Bracts* narrow with flaring tips in young shoot, becoming more oblique on older stems, green on under surface, exceeding younger buds and pressing tightly against them, reaching base of

TABLE 1

CHROMOSOME CONFIGURATIONS AND FERTILITY DATA, STRAINS FROM CALIFORNIA

Strain	Chromosome Configuration		Seed Germination %	Good Pollen %
	1st generation	Later generations		
Dalton .. .	7 pairs (2 pls.)	7 pairs	93–100	—
Devil's Gate. .	7 pairs (8 pls.) → ⊙ 4 (1 pl.)	7 pairs	65–75	78.6
franciscana. .	(probably ⊙ 4)	7 pairs ↗ ⊙ 4 ↘ ⊙ 4	—	—
Hall 21	7 pairs (5 pls.) → ⊙ 4 (1 pl.)	7 pairs	70–92	84.1
Hall 30..	7 pairs (1 pl.) ⊙ 4 (2 pls.) ↗	7 pairs ⊙ 4	86–96	91.9
Hall 34.. ...	7 pairs + fragment (1 pl.) ⊙ 4 (2 pls.) 2 ⊙s 4 (2 pls.) ⊙ 6 (1 pl.)	7 pairs ⊙ 6	62–75	88 0
Heusi	⊙ 4 (1 pl.) → 2 ⊙s 4 (2 pls.)	⊙ 4 → 7 pairs	68–76	94.3
hookeri	(probably 7 pairs)	7 pairs	—	—
Johansen. . .	7 pairs (8 pls.)	7 pairs	99	88.5
Mateo... ..	7 pairs (3 pls.) → ⊙ 4 (1 pl.) ⊙ 8 (1 pl.)	7 pairs	92–100	94.8
Mono....	7 pairs + extra (2 pls.) → ⊙ 4 (2 pls.)	7 pairs + extra	78–100	82.9

cone of earliest mature buds. *Buds* up to 8.5 cm. long (ovary 1. hypanthium 3. cone 4 cm.). moderately slender, rather thick-skinned; ovary red papillate, hypanthium green cone yellow; cone densely hairy, with both glandular and spreading pubescence; bases of long hairs often greatly enlarged and confluent, especially along angles of cone. giving a tufted appearance; tips moderately long and slender, appressed. *Flowers* up to 8 cm. across when fresh; petals broader than long (*e.g.*, 4 x 3.8 cm.). with shallow notch, lacking tooth; style long. *Fruits* large (3-3.5 cm.).

The elongate, narrow flowering tips, with erect bracts pressing inward in the middle and flaring above, are distinctive.

Chromosome Configuration.—Two plants of the first generation, one of the third and 2 of the fourth. have been examined cytologically; all of these have shown 7 pairs.

Pollen counts.—Through inadvertence, pollen counts have not been made of this form.

2. "Devil's Gate"

Pedigree.—Seed was collected by Dr. A. H. Sturtevant in February, 1930 from a single open pollinated plant found at Devil's Gate, near Pasadena, Calif. From a part of this seed a selfed line has been carried on by the writer, with cultures in 1930, 1931, 1933 and 1934. The first family showed a considerable amount of variation, involving a number of characters, most of which has been lost in later generations (Fig. 1).
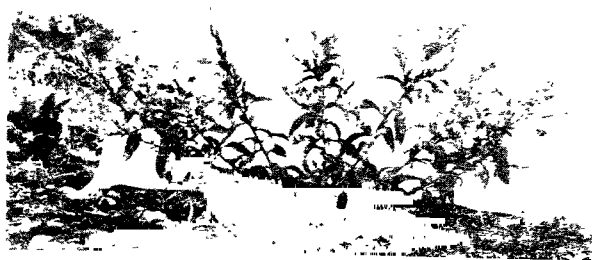
FIG. 1. *Oenothera* "Devil's Gate."

Characterization.—The following description applies to the first generation grown from the original seed. *Seed* small, darkish brown; seed germination 65.5-75 per cent. *Habit.* Central shoot present, or more often absent; branching abundant or restricted, but on the

whole less striking than in *Dalton.* *Leaves* in some plants light green. darker green in others, occasionally greyish, due to pubescence; quite broad. though varying in breadth and length (22 x 6 cm. to 24 x 4.5 cm.). varying also in amount of crinkling and wavyness; midribs white in some, faintly pink to red in others; one plant with erect marginal hairs *(ee)*, the remainder with appressed hairs (at least one plant *Ee*). *Stems* varying in amount of diffuse pigment below (some solid red), presence or absence of pigment at tips, presence or absence of red papillae. *Bracts* with or without red pigment beneath, and showing variation in the degree to which they were appressed to bud and fruit. In some, the latter was a striking feature. the bracts remaining erect and closely appressed to fruits until these were well grown. In others, the bracts were erect below. but flaring widely above. resulting in obconical tips. Flowering tips narrow, not very elongate. *Buds* ca. 8.5 cm. long (ovary 1. hypanthium 3.5, cone 4 cm.), ovary with or without red papillae, hypanthium green, cone yellow with faint traces of diffuse scarlet. more slender and tapering than in *Dalton;* both glandular and spreading pubescence present. less dense than in *Dalton*, the long hairs often greatly swollen at base. Sepal tips long, delicate, appressed (shorter in one plant). *Flowers* up to 7.5 cm. across when fresh. Petals much broader than long (*e.g.*, 3.5 x 2.5 cm.). with shallow notch, lacking a tooth. Style long, stigma lobes delicate. Fruits 3 cm. long, slender, shorter and stouter in one plant. Blooms early in season.

The plant of the first generation selected to carry on the strain (no. 9) lacked a central shoot; had broad, almost flat rosette leaves with traces of red in midribs and bent hairs (*Ee*, as shown by hybrids); broad, rather wavy cauline leaves and bracts; the latter slightly reddened beneath, or green. erect below, flaring widely above especially in younger tips; stems brilliant red more or less throughout, red at tips; sepal tips long, fruits long. Second and third generations continued to show variations in leaf breadth. foliage color and amount of pigmentation in stem and bract, but bred essentially true in other characters. The fourth generation showed essential uniformity in all characters, having broad, slightly greyish leaves, solidly pigmented stems. and essentially green bracts. *Devil's Gate* is more robust than *Dalton*, from which it differs also in having broader leaves, broader flowering tips, and less hairy buds with traces of pigmentation in the cones.

Chromosome Configurations.—Nine plants of the first generation were examined, of which 8 showed 7 pairs, and one had ⊙ 4 and 5 pairs. The plant selected as parent for the following generation had 7 pairs. One plant of the second generation. one of the third, and 2 of the fourth generation also showed 7 pairs.

Pollen count.—Good 1996, shrunken with contents 236, empty 307.   Total 2539.

3. "HALL 21"

Pedigree.—Seed was collected in 1930 by the late Dr. H. M. Hall (coll. no. 13021), from plants growing at Julian, Calif., in the Cuyamaca Mts.   From this source a selfed line has been carried on, and cultures have been grown each season, beginning with 1931. While uniform in many characteristics, and quite distinctive in appearance, a certain amount of independent segregation has been observed, as evidenced from the following description.

Characterization (First Generation).—*Seeds* medium in size, dark brown.   Seed germination 70–92 per cent.   *Habit.*   Plants tall (up to 170 cm. in Baltimore), with or without central shoots; rosette branches erect, with many short secondary branches, and long internodes; the plants seem not to be densely foliose, because of the long internodes and narrow leaves.   *Leaves* light to bright green, more or less crinkled in some, varying somewhat in breadth, but on the whole rather narrow, slightly toothed; margins reddened, marginal glands green, except in older leaves, marginal hairs erect (4 pls.) or appressed (11 pls.), red flecks absent; midribs white in some, distinctly reddened in others.   *Stems* with very long internodes, basal portion red in some, scarcely red in others, stem color correlated with midrib color; tips strongly reddened in some, scarcely reddened in others; long hairs few (in one plant none), fine felty pubescence abundant in some, giving whitish appearance, absent in others; red papillae few or none (in one case, absence possibly due to lack of long hairs, in another case, long hairs present but red papillae absent).   *Bracts* narrow, erect, their bases appressed to buds, flaring at tips, as long as first mature buds, strongly reddened beneath in some, scarcely reddened in others.   Floral tips narrow, compact, flat-topped, elongated, mature flowers far below tip (as much as 20 cm.), by reason of long internodes.   *Buds* rather slender, up to 8 cm. long (ovary 1, hypanthium 3.5, cone 3.5 cm.); ovary sparsely papillate, hypanthium reddened when cone colored (in one plant, hypanthium colored, cone green), cone with rather poorly developed color on the whole, ranging from none at all in 2 plants to fairly definite stripes on others; one plant with entirely green buds; cone color independent of stem tip color, but correlated with bract color; long hairs few to numerous usually pointing slightly forward; close short hairs numerous; bases of long hairs considerably enlarged in some cases; sepal tips fairly long, rather delicate, appressed or slightly parted below, appressed above.   *Flowers* up to 7 cm. across when fresh.   Petals broader than long (e.g., 35 x 25 mm.), shallow

tooth in notch, straw-colored when withered.   Style long. stigma lobes short.   *Fruits* showing variation in different plants in length (2 to 3 cm.), color (bright to grey-green) and presence or absence of red stripes.

In summary, the first generation of this race showed variation in respect to the color of midribs, stem (both basal and tip), bracts, cone and fruits; presence or absence of red papillae; character of marginal hairs; hairiness of stem; fruit size and coloration.   Except in the cases of basal stem and midrib color, and bract and cone color, noticeable correlations between splitting characters were absent.   Most of the characters showing segregation were quantitative characters, and clear-cut segregations were difficult to obtain. In respect to marginal hairs, however, sharp segregation was seen, there being 11 plants with appressed hairs to 4 with erect hairs. Evidence from outcrosses indicates that erect hairs is due to a single recessive gene.

The plant which became the parent of subsequent generations (no. 6) had a strong central shoot, slight evidence of red in midribs, erect marginal hairs, moderate development of basal stem color, brightly reddened stem tips and bracts, few red papillae, distinct red stripes on the cone, grey-green and red-striped fruits.   The second generation behaved like the first with respect to segregation of all of these characters, except erect marginal hairs, for which it and subsequent generations have bred true.   Segregations were not analyzed in the third generation, but in the fourth, variation was still observed in certain particulars, as follows: in the small family of 10 plants one plant had almost wholly green and smaller buds (slight traces of color), green bracts, but brilliant red midribs and a vivid scarlet coloration on the upper half of stems and on ovaries, associated with many red papillae.   Other plants had purple-tipped stems, mere traces of midrib color, and dull cone and bract coloration.   Two plants showed red stripes in the fruits.

Chromosome Configurations.—Five plants of the first generation showed entirely paired chromosomes, while one plant had ⊙ 4 and 5 pairs.   The plant which was selected as parent for later generations had 7 pairs, and this configuration was therefore found in 2 plants of the second generation as well as in 2 plants of the third generation.

Pollen Count (1 plant).—Good 212, shrunken with contents 5, empty 35.   Total 252.

4. "HALL 30"

Pedigree.—Seed was received from the late Dr. H. M. Hall, who collected it along Mill Creek in the San Bernardino Mts. in 1930

(coll. no. 13030). A selfed line was begun in 1931, and has been
continued with cultures in 1932 and 1934. This race is very similar
to *Hall 21*, and like it, has shown considerable variation. In fact,
the differences between these two races have not been greater than
the differences observed between individuals within each race
(Fig. 2).

    Characterization (First Generation).—This family showed split-

FIG. 2. *Oenothera* "Hall 30."

ting in many of the characters which were inconstant in *Hall 21*,
including stem color (basal and terminal), presence of red papillae,
midrib color, leaf breadth and flatness, position of marginal hairs,
color of bract and cone, and length, hairiness and color of fruit.
Like *Hall 21*, the race was characterized on the whole by tall habit,
long internodes, erect appressed bracts with flaring tips, and con-
sequent narrow truncated floral apices.

    Seeds smallish, red brown. Seed germination 86–96 per cent in
different cultures. *Habit*. Plants up to 135 cm., central shoot
present or absent, rosette branches erect and tall. *Leaves* moderate
in width (broader than in *Hall 21*), mostly flat; midribs white to
red, marginal hairs erect or appressed (9 *ee*. 6 *E*); red flecks present.
Stems with long internodes; basal color present to almost absent,
tips red in all, but in varying degree, red papillae numerous to none,
depending upon presence or absence of long hairs. *Bracts* reddened

or bronzed in all, but in varying degree. Floral tips narrow, elongate, truncate, with tightly appressed bracts, flaring above. *Buds* slender, up to 10.5 cm. (ovary 1, hypanthium 4.5, cone 5 cm.); ovary with or without red papillae, hypanthium somewhat reddened, cone color evenly diffused, light salmon to deep scarlet. Glandular and spreading pubescence present, the latter nearly horizontal, varying in amount. Sepal tips tending to flare in the middle, converging, or failing to meet at tip. *Flowers* up to 8 cm. across when fresh. Petals slightly broader than long (*e.g.*, 32 x 28 mm.), tooth not uniformly present in notch, petals rich orange-red when withered. Style long. *Fruits* long and narrow (4 cm.) to shorter and stouter (3 cm.), greyish-green or clear green, some with red stripes.

The first generation plant chosen to carry on the line had erect marginal hairs, white or barely tinged midribs, weak stem coloration, many red papillae, bracts and cones with color of moderate intensity, and short fruits. Leaves and stems were grey, with a fine downy pubescence. The second and third generations have bred essentially true for these characters. Less variation has thus been seen in this race than in *Hall 21* in later generations. At present, *Hall 30* differs from *Hall 21* chiefly in having broader leaves, greyer foliage and stems, and less anthocyan pigmentation in stems, but more in bracts and cones.

A close correlation was seen in this, as in other cultures, between midrib color and the color of stems. There were 10 plants which were classified as having white midribs, 10 which had red midribs, and 3 which were doubtful. Of the 10 with white midribs, all showed very little color in the lower part of the stems; of the 10 with red midribs, all had vivid stem coloration. Of those classified as doubtful, 1 had vivid stems, the other 2 had weak coloration.

Chromosome Configurations.—Two plants had ⊙ 4 and 5 pairs, and 1 plant had entirely paired chromosomes. The plant chosen to carry on the strain was one with ⊙ 4. In the second generation, 2 plants were examined, one of which had ⊙ 4, the other 7 pairs. A third generation derived from the plant with ⊙ 4 had 3 plants which were examined, all of which had ⊙ 4.

Pollen Count (3 pls.).—Good 600, shrunken with contents 28, empty 25. Total 653.

5. "Hall 34"

Pedigree.—Seed was collected in 1930 by the late Dr. H. M. Hall, near Bear Valley, in the San Bernardino Mts., Calif. (coll. no. 13034). From this seed a first generation was grown in 1931 and a second in 1932. Another family from first generation seed was grown in 1934.

Characterization (First Generation).—Seeds small. dark brown. Seed germination. in different years, 62 per cent. 31 per cent. 75 per cent. *Habit.* Plants rather low (60-65 cm.). without central shoots, the rosette branches spreading rather widely from well-developed rosettes. *Leaves* relatively broader than in *Hall 21* or *Hall 30*, smaller; dark green, more or less crinkled and wavy at base of old leaves. a typical rosette leaf 28 x 4 cm.; midrib white, marginal hairs bent in most (straight in one plant). *Stems* delicate. slightly to brightly reddened below, greener above. tips red in 8 plants, green in 4 plants; red papillae numerous in 5 plants. few in 3. none in 4 plants; all plants with long hairs; papillae absent in plants with green stem tips. *Bracts* upright. closely appressed against buds with flaring tips, as in *Hall 21* and *Hall 30*. reaching middle of cone of first mature buds; bronzed beneath in all plants, whether stems red or green-tipped. *Buds* slender. 7-8 cm. long (ovary 1, hypanthium 3-4. cone 3-3.5 cm.). red papillae on ovary when on stem. hypanthium more or less reddened in all. quite intense in some; cone coloration evenly and faintly diffused in 4 plants, rather deeply and evenly diffused in 6 plants; hairs fairly numerous. pointing slightly forward, some plants with shorter and fewer hairs. others with more numerous hairs with confluent bases. Sepal tips bowed in middle, converging at tips, or tips failing to meet; green, delicate. *Flowers* 6.5 cm. across when fresh. petals broader than long (*e.g.*, 3.5 x 2.8 cm.), usually with tooth in notch. Style long. Fruits 2 cm. long, rather stout, occasionally with tinges of red.

Hall 34 is a plant of the *Hall 21* or *Hall 30* type. but smaller, with much more delicate parts. and a more spreading habit. The plant which was selfed to give the second generation had purpled leaf margins. erect marginal hairs. red stems. numerous papillae, colored stem tips and bracts, deeply colored bud cones. strongly bowed sepal tips and a circle of 6 chromosomes. The second generation (both the 1932 family and the 1934 family) was quite uniform in appearance, reproducing the characters of the first generation parent.

Chromosome Configurations.—Six plants of the first generation were examined. and among them were found 4 configurations. One plant showed ⊙ 6 and 4 pairs (the parent of the second generation), 2 plants had ⊙ 4 and 5 pairs; 2 plants had 2 ⊙s of 4 and 3 pairs, and 1 plant had 7 pairs plus a fragment. The cytological evidence suggests that this strain has suffered considerable hybridization in recent times. and that it is far from being homogeneous.

In the second generation (1932 family). 3 plants showed the parental ⊙ 6 and one had 7 pairs. indicating that at least one half of the circle was alethal. The high percentage of good pollen suggests that lethals are absent in this material.

Pollen Count (4 pls.).—Good 800, shrunken with contents 35, empty 75. Total 910.

6. "HEUSI"

Pedigree.—Seed was collected by Mr. Wm. Heusi in August, 1930, at Mather, Calif., and sent to the writer by Dr. H. M. Hall. The first culture was grown in 1931, and there have been cultures from selfed seed in 1932, 1933 and 1934. The strain has shown some variation, both in phenotypic characters, and in chromosome configuration, analyses of which have been made in each of the first two generations.

Characterization (First Generation).—*Seeds* smallish, red-brown. Seed germination 68–76 per cent. *Habit.* Plants 70–80 cm. high; central shoot absent, the relatively few rosette branches widely spreading from a strong rosette. *Leaves* dark green, slightly toothed, margins more or less reddened in young leaves, midribs white, marginal hairs appressed: varying in width and length, but all rather broad, often obtuse (range 27 x 6.25 to 34.5 x 5.5 cm. for rosette leaves); varying also in crinkling. *Stems* scarcely reddened below, or brilliant red, red papillae few, tips reddened in all. Floral tips few flowered, obconical; flat-topped when young, rather compact. *Bracts* reddened below, or essentially green, scarcely reaching cone of first mature buds. *Buds* moderately stout to slender, 7–8 cm. long (ovary 1, hypanthium 3–3.5, cone 3–3.5 cm.); ovary red papillate, hypanthium green to deeply red, cone with mere trace of color to deep red: long hairs fairly numerous, glandular pubescence present; sepal teeth long, slender, more or less appressed. *Flowers* up to 7 cm. across when fresh; petals broader than long (*e.g.*, 3.5 x 2.75 cm.), with broad tooth in notch. Style long. *Fruits* long, slender (4 cm.), often tinged with diffuse red when young (shorter in pl. 9). Plants bloomed late in season.

Three plants of the first generation were selfed, but subsequent generations have been derived from but one plant (no. 8), although no. 9 was used in some outcrosses. Plant no. 8 had large, rather broad leaves with little crinkling and little marginal coloration: little coloration of the stem, scarcely reddened or green bracts, lightly pigmented bud cones, large flowers and long fruits. The progeny of this plant have bred essentially true to the characters of the parent.

Heusi shows resemblance to *Devil's Gate* and *Dalton*, but is less robust in our climate, has less stem pigmentation, and differs in other minor details.

Chromosome configurations were determined for three plants of the first generation. Two plants had 2 ⊙s of 4 and 3 pairs, and

one plant had ⊙ of 4 and 5 pairs. Two plants in the second generation, derived from the first generation plant with ◌ 4, showed each ⊙ 4 and 5 pairs. A single plant of the third generation yielded cytological material. It had 7 pairs.

Pollen Count (3 pls.).—Good 699, shrunken with contents 28, empty 14. Total 741.

7. "JOHANSEN"

This strain was originally called "T & G" (Cleland 1931). Since it probably does not represent the original *hookeri* T & G, however, its designation has been changed.

Pedigree.—A single rosette was collected along the roadside between Nicholas and Yuba City, Sutter Co., Calif., in November, 1927. Herbarium specimens of the original group of which this plant was a member are in the Dudley Herbarium (Stanford University), C. B. Wolf no. 1435. The plant bloomed in Palo Alto the following summer. Seed obtained from this plant was probably the result of self-fertilization. inasmuch as the nearest Onagraceous individual was more than 1000 m. away. Some of this seed was sent me by Dr. D. A. Johansen and the first culture was grown in 1930. The strain has been maintained in selfed line since then, with a generation each year. It has been marked by entire uniformity (Figs. 3, 4).

Characterization.—*Seeds* of moderate size, dark brown. Seed

3   4
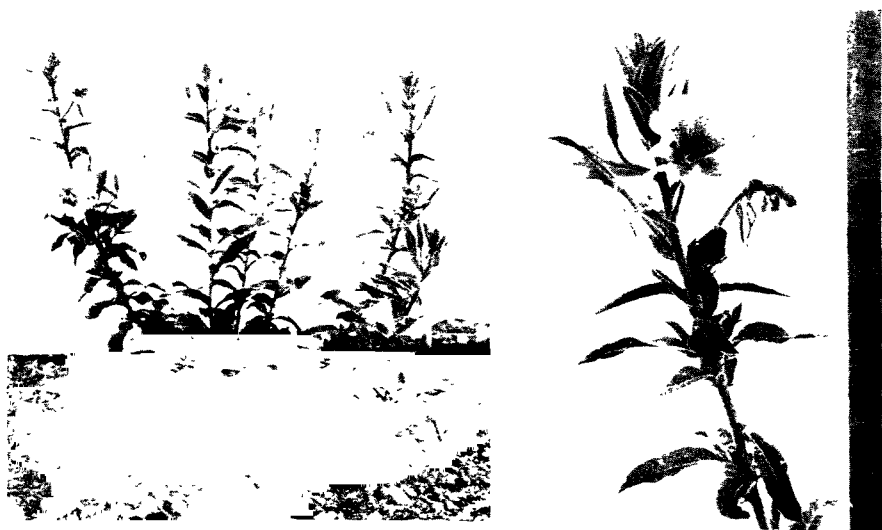
FIGS. 3, 4. *Oenothera* "Johansen."

germination (average for 5 years) 99.47 per cent. *Habit.* Plants ca. 70 cm. high at Baltimore, forming rosettes; central shoot present or absent; when present, not much taller than the erect rosette branches; not much branched. *Leaves* moderately broad (typical rosette leaf 23 x 4.5 cm.), light green, somewhat crinkled and wavy, soft to the touch by reason of fine pubescence; with white midribs, erect marginal hairs (*ee*), green marginal glands; the margins them-selves slightly tinged with purple in young leaves, sub-entire; red flecks none; cauline leaves long, moderate in width. *Stems* stout, slightly reddened below, green above, tips red, with both long and short pubescence; red papillae present, internodes long and rela-tively few. *Bracts* oblique in young tips, slightly flaring, slightly to moderately reddened on under surface, large, much exceeding young buds, the earliest often equalling first mature buds. End of spike obconical, flat-topped, rather broad, loose. *Buds* up to 10 cm. long (ovary 1, hypanthium 4, cone 5 cm.), slender; the largest buds of any California form so far described; red papillate, hypanthium tinged with light red, cone with broad red stripes; both spreading and glandular pubescence abundant; sepal tips long, delicate, some-what appressed. *Flowers* up to 10 cm. across when newly opened; petals broader than long (5 x 4.5 cm.), usually with broad tooth in notch; style long, stigma lobes delicate. *Fruit* 4 cm. long, moderate in width, green, often with red stripes.

This race differs from the *hookeri* of de Vries, being larger and stouter; with broader, more crinkled, more softly hairy, lighter green, less toothed and white-veined leaves; longer, more slender, less pigmented buds, with longer, more delicate sepal teeth; larger flowers and greener stems.

Chromosome Configuration.—All plants which have been exam-ined cytologically have shown 7 pairs in meiosis. This includes 8 plants of the first generation, and 3 plants of the 5th generation.

Pollen Count (5 pls.).—Good 881, shrunken with contents 19, empty 95. Total 995.

8. "MATEO"

Pedigree.—Seed was collected in November, 1930, by Dr. D. A. Johansen, from a plant growing at Pt. Pascadero, San Mateo Co., Calif., just back of the coastal sand dunes, and along a slightly saline slough. Starting from this seed, the writer has maintained a selfed line, with cultures each year, beginning with 1931. The first family showed variation in several characters, the most striking segregation being in habit, as will be indicated in the description. Later generations have continued to show the splitting in habit, and in certain other minor characters (Fig. 5).

FIG. 5.   *Oenothera* "Mateo"; young tip of dwarf plant.

Characterization.—*Seeds* small to moderate, darkish brown. Seed germination 92 per cent to 100 per cent in different sowings. *Habit.* All but one of the first generation plants were characterized by a dwarf habit, with a central shoot, having very short internodes, numerous side branches and broad leaves, the plant as a whole being conical, compact and densely foliose, with the buds rising above the apex of the spike when still young; not over 50 cm. in height (said by Johansen to have been $5\frac{1}{2}$ feet tall in their native habitat). The one exceptional plant had narrower leaves, no central shoot, but widely spreading rosette branches, with long internodes, rising to a height of 70 cm., the buds being inserted far below the stem tips when mature. In subsequent generations from selfed plants of the dwarf type this splitting in habit has been repeated, 3 talls being found in a total of 24 plants that bloomed in 1932. In 1934, progeny were grown from selfed plants of both the dwarf and the tall type. They became unfortunately badly infected with Septoria blight, so that only 2 plants from dwarf parents and one from a tall parent bloomed. Both plants from dwarf parents were dwarf, and the plant from a tall parent was tall. It seemed clear, however, from the breadth of the rosette leaves of those which did not bloom that the progeny of the tall plant was entirely narrow-leaved, and therefore probably tall, whereas the progenies of the dwarfs included a few narrow-leaved individuals, and were therefore not entirely dwarf. *Leaves* slightly crinkled at the base in most, slightly toothed, dark green, hairy; midribs rarely white, mostly with traces of pink;

red flecks absent; margins strongly purpled, even in mature leaves; glands red, marginal hairs appressed. *Stem* stocky, with short internodes (or delicate, with long internodes, in tall type), reddened below, green above, occasionally almost solidly reddened, purple at tips; red papillae large and numerous, more or less elongate. *Bracts* in dwarf type large, broad, spreading, ¾ as long as first mature buds; narrower in tall type, relatively smaller; reddened below, hairy. *Buds* stout, up to 8.5 cm. long (ovary 1, hypanthium 3.5, cone 4 cm.); ovary with red papillae, hypanthium often as red as cone, cone bright to dull salmon red, tips green; densely pilose, glandular pubescence also present. Sepal tips short, thick, appressed, bristly-hairy. *Flowers* 5–6.5 cm. across when fresh, opening early in evening; petals broader than long (*e.g.*, 3.75 x 3 cm.), with slight to decided tooth in notch; style long, stigma lobes delicate. *Fruit* stout, up to 4 cm. long, green, often with red stripes and many red papillae.

The most striking features of *Mateo* are the compact habit of the plant and the occasional segregation of plants with long internodes. Apart from this variation, minor differences in degree of crinkling of leaves, and amount of coloration of stem and bract were found in the first generation. These have largely vanished in later generations, all plants having rather flat leaves and well developed pigmentation.

Mateo differs markedly from any other form brought under observation, especially in habit. Its closest affinities are probably with *franciscana* and *hookeri* deV., the former of which especially is not unlike the elongate form of *Mateo*. In bud characters, *Mateo* shows the stout, cylindrical shape of the *hookeri* buds, and the dense long pubescence of *franciscana*.

Chromosome Configurations.—In the first generation, one plant showed ⊙ 8 and 3 pairs (the plant with the tall habit), one plant had ⊙ 4 and 5 pairs, and 3 plants had 7 pairs. One of the last became the parent of subsequent generations. In 1932, 3 plants (including 2 dwarf and 1 tall plant) showed 7 pairs, and in 1934, 2 plants (1 dwarf and 1 tall) showed the same configuration.

Pollen Count (3 pls.).—Good 648, shrunken with contents 13, empty 22. Total 683.

9. "Moxo"

Pedigree.—Seed was collected by Dr. D. A. Johansen at a point 2½ miles north of Chris Flat, along the West Walker River, Mono Co., Calif. This is on the east slope of the Sierras, at an elevation of about 9000 feet. From this seed, the writer has established a selfed line, with cultures each year, beginning with 1931. The race

has shown a certain amount of variation, as indicated below (Fig. 6).

Characterization (First Generation).—Seeds moderately small, dark brown. Seed germination 78–100 per cent. *Habit.* Plants 70 cm. tall at Baltimore, most plants with central axis, which in only 2 cases was higher than the rather erect rosette branches; plants bushy but rather open, with delicate stems and leaves. *Leaves* bright clear green, relatively flat and uncrinkled; margins reddened at least in young leaves, glandular teeth red, marginal hairs ap-

FIG. 6. *Oenothera* "Mono."

pressed; midribs pink to bright red; red flecks present in some individuals; variation in leaf breadth in different plants, mostly rather broad (rosette leaves ave. 20 x 5 cm.). *Stems* slender, reddened below, or often throughout, purple-tipped, with relatively few red papillae. *Bracts* narrow or moderately broad, more or less reddened beneath, upright with slightly flaring tip, or oblique and widely flaring, about equal to or slightly exceeding young buds; reaching to base of cone of earliest mature buds. Floral tip small, delicate, relatively few-flowered, obconical or narrow. *Buds* up to 7 cm. long (ovary 1, hypanthium 3, cone 3 cm.), slender or moderately stout; ovary with red papillae, hypanthium distinctly reddened or green, cone more or less evenly reddened, the amount of coloring varying in different individuals, intense in some; sepal tips green; cone softly and moderately hairy, both long spreading and short

glandular hairs present. former not very abundant; sepal tips short. delicate. appressed to slightly parted in the mid region. *Flowers* 5.5 to 7 cm. when fresh. opening late in the evening.   Petals slightly broader than long. with tooth in notch.   Style long, stigma lobes moderate in length, delicate.   *Fruits* 3–4 cm. long, rather slender in most plants, shorter and slightly stouter in the plant which became the parent of succeeding generations.

Variations were present in the first generation with respect to presence or absence of central shoot, leaf breadth, cone color and fruit size.   Subsequent generations were derived from a plant with short central axis, leaves of moderate width, bract and cone pigmentation of moderate intensity, short sepal tips and short fruits. Variations in leaf breadth have not been noticeable in later generations. but variation in cone and bract color, and character of central shoot have persisted.   One plant in 1932 had perfectly green buds and bracts.   Selfings from this plant and from one with red buds and reddened bracts were grown in 1934.   In the family from the green-budded parent, only 2 out of the 9 plants which bloomed had green buds and bracts.   The progeny of the red-budded plant, on the other hand, included more green- than red-budded plants (2 red, 3 green).   This is the sort of result that might have been expected had the red-budded parent been heterozygous for a pigmentation factor, and pure for the recessive allele of an inhibitor of pigmentation, while the green-budded parent was heterozygous for the inhibitor at the same time that it carried the pigmentation factor.

Chromosome Configurations.—Two first generation plants showed ⊙ 4 and 5 pairs.   Two other plants had 7 pairs, plus extra chromosomal material; one of these showed a set of 3 extra half-sized chromosomes, the other an extra pair of diminutive chromosomes. This, with the case found in *Hall 34,* is the first time that extra chromosomal material has been found in wild strains of *Onagra.* A fuller description of the cytological situation is reserved for a later paper.

The first generation plant which was used for selfing had 7 pairs, plus an extra pair of chromosomes.   Two plants in the next generation were examined cytologically and both showed the extra pair. Each of these was selfed and yielded a third generation progeny. From one of these families, 3 plants were studied cytologically, and all had the extra pair; from the other, 9 plants were examined. of which 8 had the extra pair and the ninth had but a single extra. All of these plants, apart from the extra diminutive chromosomes, had 7 pairs.

Pollen Count (2 pls.).—Good 471, shrunken with contents 18, empty 79.   Total 568.

TABLE 2

CHROMOSOME CONFIGURATIONS OF F_1 HYBRIDS, BOTH OF WHOSE PARENTS WERE CALIFORNIA RACES

Cross	Complex-combination	Chromosome-configuration	
Dalton × Devil's Gate .	^{h}Dalt.^{h}Dev.G.	7 pairs	(3 pls.)
Dalton × hookeri...	^{h}Dalt.^{h}hook	⊙ 4	(3 pls.)
Dalton × Johansen.....	^{h}Dalt.^{h}Joh.	7 pairs	(3 pls.)
Devil's Gate × Dalton...	^{h}Dev.G.^{h}Dalt.	7 pairs	(3 pls.)
Devil's Gate × franciscana	^{h}Dev.G.^{h}franc.	⊙ 4	(3 pls.)
Devil's Gate × hookeri....	^{h}Dev.G.^{h}hook.	⊙ 4	(3 pls.)
Devil's Gate × Johansen	^{h}Dev.G.^{h}Joh.	7 pairs	(3 pls.)
Hall 21 × Dalton ...	^{h}Hall 21.^{h}Dalt.	7 pairs	(3 pls.)
Hall 21 × franciscana...	^{h}Hall 21.^{h}franc.	⊙ 4	(3 pls.)
Hall 21 × Hall 34 ...	^{h}Hall 21.α (?) Hall 34	⊙ 4	(6 pls.)
Hall 21 × Mateo (pl. 10')	^{h}Hall 21.^{h}Mat.	7 pairs	(2 pls.)
Hall 21 × Mono (8 prs.) .	^{h}Hall 21.^{h}Mono	7 pairs	(3 pls.)
Hall 30 × Hall 21..	β Hall 30.^{h}Hall 21	7 pairs	(1 pl.)
	α Hall 30.^{h}Hall 21	⊙ 4	(1 pl.)
Hall 30 × Hall 34	α Hall 30.α Hall 34	7 pairs	(1 pl.)
	α Hall 30.β Hall 34, or β Hall 30.α Hall 34	⊙ 4	(1 pl.)
Hall 30 × hookeri..	α Hall 30.^{h}hook.	7 pairs	(2 pls.)
	β Hall 30.^{h}hook.	⊙ 4	(1 pl.)
Hall 30 × Mateo...	α Hall 30.^{h}Mat.	⊙ 4	(2 pls.)
	β Hall 30.^{h}Mat.	7 pairs	(1 pl.)
Hall 30 × Mono (8 prs.)	α Hall 30.^{h}Mono	⊙ 4, 6 prs.	(1 pl.)
	β Hall 30.^{h}Mono	8 pairs	(1 pl.)
Hall 34 × Devil's Gate .	α (?) Hall 34.^{h}Dev.G.	⊙ 4	(5 pls.)
Hall 34 × hookeri...	α Hall 34.^{h}hook.	7 pairs	(2 pls.)
	β Hall 34.^{h}hook.	⊙ 6	(1 pl.)
Hall 34 × Mateo...	α (?) Hall 34.^{h}Mat.	⊙ 4	(3 pls.)
Hall 34 × Mono (8 prs.)	α (?) Hall 34.^{h}Mono	⊙ 4, 6 prs.	(4 pls.)
Heusi (⊙ 4) × Devil's Gate	α Heusi.^{h}Dev.G.	7 pairs	(1 pl.)
	β Heusi.^{h}Dev.G.	⊙ 4	(2 pls.)
Heusi (⊙ 4) × Hall 21.	α Heusi.^{h}Hall 21	7 pairs	(2 pls.)
	β Heusi.^{h}Hall 21	⊙ 4	(1 pl.)
Heusi (2 ⊙s 4) × Hall 30	α Heusi.α Hall 30, or β Heusi.β Hall 30, or δ Heusi.β Hall 30	⊙ 4	(1 pl.)
	β Heusi.α Hall 30. or γ Heusi.β Hall 30	2 ⊙s 4	(1 pl.)
	γ Heusi.α Hall 30	⊙ 4. ⊙ 6	(1 pl.)

TABLE 2.—*Continued*

Cross	Complex-combination	Chromosome-configuration
Heusi (2 ⊙s 4) × *Hall 34*......	α *Heusi*.β *Hall 34*(?),or α *Heusi*.α *Hall 34*, or γ *Heusi*.β *Hall 34* (?)	⊙ 4 (5 pls.)
	γ *Heusi*.β *Hall 34*(?),or β *Heusi*.α *Hall 34*, or β *Heusi*.β *Hall 34*(?)	2 ⊙s 4 (4 pls.)
Heusi (⊙ 4) × *Mateo*........	α *Heusi*.ʰ*Mat.* β *Heusi*.ʰ*Mat.*	7 pairs (2 pls.) ⊙ 4 (1 pl.)
Heusi (2 ⊙s 4) × *Mono* (⊙ 4).	α *Heusi*.α *Mono* or β *Heusi*.β *Mono*(?) or δ *Heusi*.β *Mono*(?)	7 pairs (1 pl.)
	α *Heusi*.β *Mono*, or β *Heusi*.α *Mono*, or δ *Heusi*.α *Mono*, or γ *Heusi*.β *Mono*(?), or δ *Heusi*.β *Mono*(?)	⊙ 4 (3 pls.)
	γ *Heusi*.α *Mono*, or γ *Heusi*.β *Mono*(?), or δ *Heusi*.β *Mono*(?),or β *Heusi*.β *Mono*(?)	2 ⊙s 4 (5 pls.)
hookeri × *Devil's Gate*	ʰ*hook.*ʰ*Dev.G.*	⊙ 4 (3 pls.)
hookeri × *Johansen*........	ʰ*hook.*ʰ*Joh.*	⊙ 4 (3 pls.)
Johansen × *Dalton*........	ʰ*Joh.*ʰ*Dalt.*	7 pairs (3 pls.)
Johansen × *Devil's Gate*.......	ʰ*Joh.*ʰ*Dev.G.*	7 pairs (3 pls.)
Johansen × *franciscana deV.* .	ʰ*Joh.*ʰ*franc.*	⊙ 4 (4 pls.)
Johansen × *hookeri*..........	ʰ*Joh.*ʰ*hook.*	⊙ 4 (2 pls.)
Mateo × *Devil's Gate*..........	ʰ*Mat.*ʰ*Dev.G.*	7 pairs (3 pls.)
Mateo × *hookeri*..........	ʰ*Mat.*ʰ*hook.*	⊙ 4 (3 pls.)
Mateo × *Mono* (8 prs.)	ʰ*Mat.*.ʰ*Mono*	8 pairs (2 pls.)
Mono (⊙ 4) × *hookeri*........	(?)*Mono.*ʰ*hook.*	⊙ 4 (3 pls.)
Mono (8 prs.) × *Mateo*........	ʰ*Mono.*ʰ*Mat.*	8 pairs (1 pl.) 7 or 8 pairs, or 7 prs. plus 1 chrom. (2 pls.)
Mono (8 prs.) × *Johansen*.....	ʰ*Mono.*ʰ*Joh.*	8 pairs (8 pls.)

B. F_1 *Hybrids Between California Races*

1931: 39 *Oe.* ("*Dalton*" × "*Devils Gate*") (1930: 11, pl. 2 × 1930: 12, pl. 9).

Seed germination 96 per cent (50 seed); 15 plants transferred to field.

Height up to 1 m. Plants showed the independent variation in position of marginal hairs (9 *ee*; 6 *Ee*) and in stem coloration (7

brilliant red; 8 light red) which are characteristic of *Devil's Gate*; with respect to cone color, a less clear-cut segregation was seen: plants approached *Devil's Gate* more closely than *Dalton*, inasmuch as all had at least a trace of color. Only those plants with relatively strong cone pigmentation showed the under side of the bracts reddened. With respect to other characters, the parents were essentially similar, which similarity was carried over into the hybrids.

Segregation in cone color has not been noticed in either of the parental strains. However, the presence of such segregation in progenies of the particular *Devil's Gate* plant used in this cross indicates that it was probably heterozygous for a gene or genes affecting cone and bract color.

Chromosome Configuration.—Three plants were examined. All showed 7 pairs.

Pollen Count (1 pl.).—Good 311, empty 4. Total 315.

1931:45 *Oe.* (*"Devil's Gate"* × *"Dalton"*) (1930:12, pl. 9 × 1930: 11, pl. 2).

Only 16 seed were available, of which 13 germinated; from these, 11 plants were grown to maturity. The plants were identical with their reciprocals, showing the same type of variation in color of stem, cone and bract, and in marginal hair position (redder stems in 6, lighter stems in 4; erect hairs (*ee*) in 6, appressed (*Ee*) in 5. Segregation independent).

Chromosome configuration in 3 plants was 7 pairs. They were thus like their reciprocals.

1931:37 *Oe.* (*"Dalton"* × *hookeri deV.*) (1930:11, pl. 2 × 1930:9, pl. 11).

Seed germination 64 per cent (50 seed); 15 plants transferred to field.

Height up to 1 m. Culture essentially uniform, resembling *hookeri* more closely in habit, but approaching *Dalton* more nearly in bud characters, including shape, color of cone and bract, and pubescence.

Chromosome Configuration.—Three plants were examined. All had ⊙ 4, 5 pairs.

Pollen Count (1 pl.).—Good 266, shrunken with contents 3, empty 12. Total 281.

1931:38 *Oe.* (*"Dalton"* × *"Johansen"*) (1930:11, pl. 2 × 1930:10, pl. 1).

Seed germination 86 per cent (50 seed); 15 plants transferred to field.

Height 1 m.; the culture was uniform except in the presence or

absence of central shoot. It showed the characteristics of *Johansen* most strikingly in the soft velvety pubescence of the leaves, absence of heavy diffuse pigmentation on the stems, loose spreading character of the floral tips, increased amount of cone and bract pigment, and red stripes on the fruit. The influence of *Dalton* was best seen in the narrowness of the leaves, in the presence of confluent hair bases on the cone, and possibly in the arrangement of cone pigmentation into splotches, irregularly scattered, rather than into stripes (see pedigree 1932: 68, p. 368).

Chromosome Configuration.—Three plants were examined. They had 7 pairs.

Pollen Count (1 pl.).—Good 321, empty 34. Total 355.

1931: 51 *Oe.* (*"Johansen"* × *"Dalton"*) (1930: 10, pl. 1 × 1930: 11, pl. 2).

Seed germination 96 per cent (50 seed); 15 plants transferred to field.

In every respect, this culture was identical with its reciprocal.

Chromosome Configuration.—Three plants showed 7 pairs of chromosomes in diakinesis.

1931: 46 *Oe.* (*"Devil's Gate"* × *franciscana deV.*) (1930: 12, pl. 11 × 1930: 14, pl. 2).

Seed germination 76 per cent (50 seed); 15 plants transferred to field.

Height up to 1 m. Culture essentially uniform in all characters, except leaf breadth, in which there was an ill-defined variation. Plants resembled *franciscana* very closely in rosette characters, having broad wavy leaves. *Franciscana* influence was also seen in the presence of a considerable amount of coloration in bud cone and bract, and in the strong development of long horizontal hairs on the buds. *Devil's Gate* influence was largely seen in the narrowness of the floral tips, slimness of the buds, length of the sepal tips, and partial suppression of cone and bract color, resulting in a degree of pigmentation intermediate between that of the parents. The heterozygosity of the *Devil's Gate* parent in respect to stem color and marginal hair position was presumably masked by dominant genes in homozygous condition in *franciscana*.

Chromosome Configuration.—Three plants were examined, all of which had ☉ 4, 5 pairs.

1931: 28 *Oe.* (*franciscana deV.* × *"Devil's Gate"*) (1930: 14, pl. 2 × 1930: 12, pl. 1).

Seed germination 92 per cent (50 seed); 15 plants transferred to field.

These plants were essentially similar to their reciprocals. No study of chromosome configuration was made.

1931:43 *Oe.* (*"Devil's Gate"* × *hookeri deV.*) (1930: 12, pl. 9 × 1930: 9, pl. 3).

Seed germination 100 per cent (50 seed); 15 plants transferred to field.

Plants up to 1 m. in height, similar in habit to the parents, but intermediate with respect to most of the characters in which the parents differ, such as leaf breadth, character of flowering tip, length of sepal tips. Independent segregation was observed in stem coloration (7 bright red, 7 light red), cone and bract coloration (5 with much color, 9 with little or no color), and marginal hair position (4 *ee*, 11 *Ee*). These are characters in which *Devil's Gate* itself shows splitting, or in which the *Devil's Gate* parent was apparently heterozygous, and the inconstancy of the hybrid must be ascribed to the heterozygosity of the *Devil's Gate* parent, especially since *hookeri* deV. is known to be homozygous.

Chromosome Configuration.—Three plants were studied, and each showed ⊙ 4, 5 pairs.

1931:17 *Oe.* (*hookeri deV.* × *"Devil's Gate"*) (1930:9, pl. 3 × 1930: 12, pl. 9).

Seed germination 92 per cent (50 seed); 15 plants transferred to field. They were identical with the reciprocal and showed splitting in the same 3 characters, as follows:

more red in cones and bracts 9 { bright red stems 6(*ee* 2, *Ee* 4)
 { light red stems 3(*ee* 1, *Ee* 2)

little red in cones and bracts 5 { bright red stems 0
 { light red stems 5(*ee* 2, *Ee* 3)

Chromosome Configuration.—Three plants had ⊙ 4, 5 pairs, like their reciprocals.

Pollen Count (1 pl.).—Good 25, empty 44. Total 69.

1931:44 *Oe.* (*"Devil's Gate"* × *"Johansen"*) (1930: 12, pl. 9 × 1930: 10, pl. 7).

Seed germination 98 per cent (50 seed); 15 plants transferred to field.

Plants showed segregation in respect to cone and bract color, stem color and marginal hair position, as follows:

cone and bract darker red 5 { stems dark red 3 (*ee* 2, *Ee* 1)
 { stems lighter red 2 (*ee* 2, *Ee* 0)

cone and bract lighter red 10 { stems dark red 2 (*ee* 1, *Ee* 1)
 { stems lighter red 8 (*ee* 4, *Ee* 4)

In most other respects in which the parents differed, the hybrids were intermediate, showing, however, in striking fashion the typical *Devil's Gate* character of having the bracts appressed closely to the buds, even in anthesis.

Chromosome Configuration.—Four plants were examined; each showed 7 pairs.

Pollen Count (1 pl.).—Good 316, shrunken with contents 3, empty 12. Total 331.

1931: 52 *Oe.* ("*Johansen*" × "*Devil's Gate*") (1930: 10, pl. 6 × 1930: 12, pl. 9).

Seed germination 100 per cent (50 seed); 15 plants transferred to field. The culture resembled its reciprocal in every particular. Splitting occurred as follows:

$$\text{cone and bract darker red } 8 \begin{cases} \text{stems dark red } 4 \ (ee \ 3, \ Ee \ 1) \\ \text{stems light red } 4 \ (ee \ 4, \ Ee \ 0) \end{cases}$$

$$\text{cone and bract lighter red } 7 \begin{cases} \text{stems dark red } 2 \ (ee \ 2, \ Ee \ 0) \\ \text{stems light red } 5 \ (ee \ 2, \ Ee \ 3) \end{cases}$$

Chromosome Configuration.—Three plants were studied. All had 7 pairs.

1931: 27 *Oe.* (*franciscana* de*V.* × "*Dalton*") (1930: 14, pl. 2 × 1930: 11, pl. 2).

Seed germination 98 per cent (50 seed); 15 plants transferred to field.

Plants uniform, 70 cm. high, with strong rosettes, widely spreading rosette branches and no central shoot. In general, the culture was intermediate in those characters which distinguish the parental races, such as leaf breadth, character of floral tip, cone coloration, bud shape.

No cytological studies were made of this culture.

1931: 26 *Oe.* (*franciscana* de*V.* × "*Johansen*") (1930: 14, pl. 2 × 1930: 10, pl. 3).

Seed germination 76 per cent (50 seed); 30 plants transferred to field.

Plants uniform, 60 cm. high, with strong rosettes, spreading rosette branches and no central shoot. *Johansen* characters which were particularly noticeable were velvety pubescence of the foliage, spreading character of the floral tip, and red stripes on the ovary. *Franciscana* characters included appressed marginal hairs, deep bud and bract coloration, and general habit. Plants were intermediate in leaf breadth, bud shape and stem coloration; other characters were common to both parents.

Cytological studies were not made of this culture.

1931:53 *Oe.* (*"Johansen"* × *franciscana deV.*) (1930:10, pl. 6
     × 1930:14, pl. 2).

Seed germination 90 per cent (50 seed): 15 plants transferred to field. In every respect the culture was uniform and identical with its reciprocal.

Chromosome Configuration.—Four plants were examined. Each showed ⊙ 4, 5 pairs.

1932:68 *Oe.* (*"Hall 21"* × *"Dalton"*) (1931:65, pl. 6 × 1931:1,
     pl. 9).

Seed germination 95 per cent (100 seed): 30 plants transferred to field.

Height up to 125 cm., habit closely resembling *Hall 21*, with central shoots in some plants, rosette branches erect and tall, with long internodes, mature buds borne far below tip of floral axis. Plants also showed the pinkish midribs of *Hall 21*. Apart from these characters, and those which showed variation (see below), most features of the hybrids were common to the parents.

Variation was shown in amount of crinkling of foliage; presence or absence of central shoot; amount of coloration on the stem; bract and cone coloration: pattern of coloration on cone (whether striped or splotched); presence or absence of red stripes on fruits. In all of these characters, except cone color pattern, *Hall 21* had also shown splitting in the generation which furnished the parent of this cross, whereas *Dalton* had shown uniformity with respect to these characters. It is possible, however, that *Dalton* is heterozygous for a cone color pattern factor, which it is itself unable to express, owing to the absence of pigmentation. With the possible exception, therefore, of cone pigmentation pattern, the variation found in this hybrid should be ascribed to the female parent, which was apparently heterozygous for a number of factors. All of these characters were independent in splitting, except cone color and bract color, which, as usual, were completely correlated.

Chromosome Configuration.—Three plants were examined, and all showed 7 pairs.

1932:67 *Oe.* (*"Hall 21"* × *franciscana deV.*) (1931:65, pl. 6 × 1931:
     58, pl. 1).

Seed germination 88 per cent (100 seed); 30 plants transferred to field.

Height 150 cm., habit closely resembling *Hall 21*, with tall, erect stems, long internodes and mature buds far below tip of floral axes. Plants were intermediate between parents in leaf breadth, and width

of bud cones; showed the appressed marginal hairs of *franciscana*, and the long delicate sepal tips of *Hall 21*. A closer approach to uniformity was found in this than in the last mentioned culture, owing to the fact that the tendency of progenies of *Hall 21* (1931, pl. 6) to split with respect to stem, bract and cone color is largely masked by the presence of dominant genes for such coloration in homozygous condition in *franciscana*. Consequently, only bare indications of variation in cone color were observed, and no variation in stem or bract coloration. Splitting with respect to fruit coloration was still observed. however.

Chromosome Configuration.—Three plants were examined, and each showed ⊙ 4, 5 pairs.

1932:51 *Oe.* ("*Hall 21*" × "*Hall 34*") (1931:65, pl. 6 × 1931:67, pl. 7).

Seed germination 91 per cent (100 seed); 30 plants were transferred to field.

Plants reached 140 cm. in height, with tall, erect stems, long internodes, and mature buds far below tips of floral axes. The parents were very much alike, differing chiefly in the following respects: the *Hall 21* parent had relatively few, erect stems, weak stem color, few red papillae, red stripes on the fruits; the *Hall 34* parent had more numerous and more spreading branches, brighter red stems, more numerous papillae, and fruits devoid of pigmentation. The hybrids resembled the *Hall 21* plant in habit, had a moderate number of red papillae, showed some variation in stem color (leaning, however, toward the pollen parent), and showed splitting in cone color. There was also some variation in the degree of canescence on the stems.

Chromosome Configuration.—Six plants were examined and all showed ⊙ 4, 5 pairs.

1932:70 *Oe.* ("*Hall 21*" × "*Mateo*") (1931:65, pl. 6 × 1931:4, pl. 10).

Seed germination 85 per cent (100 seed); 30 plants transferred to field.

Plants showed the type of splitting in habit characteristic of *Mateo*. Eleven plants were tall (110–130 cm.), with central shoot and erect side branches (both tall), slender, elongated internodes, narrow floral tips, short erect bracts, mature buds not reaching the tip of the floral axis, except at the end of the growing season: 14 plants on the other hand were dwarfed (50–75 cm.), with shorter stems, short internodes, broad flat-topped floral axes, long bracts growing obliquely and flaring widely, mature buds exceeding tip of axis very early in season.

In addition, apparently due to the influence of the *Hall 21* parent, splitting was apparent in at least 3 other characters, all of which varied independently of each other, and of the segregation in habit. These characters were stem color, fruit color (17 with red stripes, 9 with no stripes), amount of fine downy pubescence on stems and fruits (15 with abundant pubescence, 11 with little or none). Some ill-defined variation in leaf breadth was also found.

With respect to other characters in which the parents differed, the plants showed an intermediate condition in bud thickness and sepal tip length, an even distribution of cone color, which was weaker than in *Mateo*, and the appressed marginal hairs of *Mateo*.

Chromosome Configuration.—Two plants were examined, both of which had 7 pairs. Both were tall plants. From other crosses involving *Mateo*, however, it is known that both tall and dwarf types have the same segmental arrangements.

1932:69 *Oe.* ("*Hall 21*" × "*Mono*") (1931:65, pl. 15 × 1931:5, pl. 10 [8 prs.]).

Seed germination 63 per cent (100 seed); 30 plants transferred to field.

Plants from 70 to over 100 cm. in height. The parental races are closely related, but differ in a number of features, the principal being height, presence or absence of central shoot, position of marginal hairs, leaf breadth, coloration of bracts, color of hypanthium and cone, presence or absence of red stripes on fruits. The hybrids showed considerable variation in height, some variation in leaf breadth, an almost unanimous absence of central shoots, and splitting in regard to bract color, hypanthium and cone color. In this splitting, a tendency was observed for those with red cones and bracts to show traces of red on fruits. On the other hand, those with brighter cones seemed to show fewer papillae on stem and ovary. Both parent races showed splitting in respect to leaf breadth, and bract and bud color.

Chromosome Configuration.—Three plants were examined, and despite the fact that the *Mono* parent had extra chromosomes, all 3 showed the normal 14 chromosomes, arranged into 7 pairs in diakinesis. Since in all other cases where a *Mono* plant with extra chromosomes was used in a cross, extra chromosomes have been found in the progeny, the presence of 7 pairs in this case suggests that possibly a mistake was made in pollination.

1932:73 *Oe.* ("*Hall 30*" × "*Hall 21*") (1931:66, pl. 1 × 1931:65, pl. 6).

Seed germination 64 per cent (100 seed); 30 plants transferred to field.

Height up to 170 cm.   The parental strains resemble each other very closely, there being no greater difference between them than was seen within the races themselves in the first generation under observation.   Naturally, therefore, the hybrids were scarcely to be distinguished from their parents except by their increased vigor. On the whole, the hybrids showed a greater development of red stem pigmentation than was shown by either parent, no doubt a cumulative effect.   Increase in stem coloration was accompanied by the appearance of pink color in the midribs, which was absent in both parents (*i.e.*, in the individuals, not the races as a whole), but which is practically always seen in California forms when stem coloration is strong enough.   The hybrids showed bowed sepal tips and a deep orange coloration in the petals after withering (both characters of *Hall 30*); they also showed purplish leaf margins (found in the *Hall 21*, but not in the *Hall 30* parent).   Like the parent races, the hybrids showed variation in the amount of cone coloration and in the presence or absence of red stripes on young fruits. All other characters displayed by the hybrids were seen in both parents.

Chromosome Configurations.—Two plants were examined cytologically.   One of these (β *Hall 30*.^{h}*Hall 21*) had 7 pairs, the other (α *Hall 30*.^{h}*Hall 21*) had $\odot$ 4, 5 pairs.

1932:50 *Oe.* ("*Hall 30*" $\times$ "*Hall 34*") (1931:66, pl. 1 $\times$ 1931:67, pl. 7).

Seed germination 5 per cent (100 seed; the seed was probably collected too young); all 5 plants transferred to field, of which 3 flowered.

The parental races differ chiefly in habit, *Hall 34* being much lower, with more spreading rosette branches.   The hybrids resembled *Hall 34* rather closely in habit, being only 60 cm. in height. The individual of *Hall 30* used in this cross showed much less red pigmentation in stem, bract and cone than did the *Hall 34* parent. In this respect, the hybrids were somewhat intermediate, leaning toward the *Hall 34* condition.

Chromosome Configurations.—Two plants were examined; one of these had 7 pairs, the other $\odot$ 4, 5 pairs.   As will be explained later, the first plant must have had the composition α *Hall 30*.α *Hall 34*. The latter might have been either α *Hall 30*.β *Hall 34* or β *Hall 30*. α *Hall 34*.

1932:77 *Oe.* ("*Hall 30*" $\times$ *hookeri deV*.) (1931:66, pl. 1 $\times$ 1931: 57, pl. 12).

Seed germination 98 per cent (100 seed); 29 plants transferred to field.

Plants up to 110 cm. in height. Culture was essentially uniform: the plants were intermediate in habit, and showed purplish leaf margins; strongly reddened stems, bracts and buds; and sepal tips of intermediate length.

Chromosome Configurations.—Three plants were examined. Two of these (α *Hall 30.* ʰ*hookeri*) had 7 pairs; one plant (β *Hall 30.* ʰ*hookeri*) had ☉ 4, 5 pairs.

1932:75 *Oe.* ("*Hall 30*" × "*Mateo*") (1931:66, pl. 1 × 1931:4, pl. 15).

Seed germination 97 per cent (100 seed); 30 plants transferred to field, all but 4 remained rosettes.

Three plants were semi-dwarf in habit, and one was tall, showing therefore the same type of segregation in habit found in *Mateo*. The tall plant in this case was not actually much higher than the semi-dwarf (70 cm.), since the latter had many more internodes than the former—about 70 nodes per branch vs. 50 per branch. Influence of *Mateo* was seen not only in the segregation according to habit, but also in increased stem color, pinkish midribs, appressed marginal hairs, stoutness of bud cones and shortness of sepal tips. *Hall 30* influence was especially seen in the weakened bract and cone coloration and in a slight tendency toward bowing of the sepal tips.

Chromosome Configurations.—Two plants showed ☉ 4, 5 pairs (α *Hall 30.* ʰ*Mateo*); one plant had 7 pairs (β *Hall 30.* ʰ*Mateo*).

1932:76 *Oe.* ("*Hall 30*" × "*Mono*") (1931:66, pl. 1 × 1931:5, pl. 10 [8 prs.]).

Seed germination 64 per cent (100 seed); 30 plants transferred to field.

Height up to 115 cm. Except in habit, and in the different degree of development of anthocyan pigment, the races involved in this cross are quite similar, having the same characteristic shape of floral tip and other important features in common. With respect to the characters in which the parents differed, we find the influence of *Mono* particularly in the widely spreading habit of the rosette branches, the intense reddening of stems, the pinkish midribs and appressed marginal hairs, and the deep pigmentation of bracts and bud cones. Influence of *Hall 30* was best seen in the long, delicate, and occasionally bowed sepal tips, and in the deep orange coloration of the withered petals.

Variation was noted in leaf breadth (influence of *Mono*), and in the presence or absence of red stripes on the fruits (influence of *Hall 30*).

Chromosome Configurations.—Two plants were examined. One

of these (α *Hall 30.**ʰMono*) had ⊙ 4, 6 pairs, the other (β *Hall 30.ʰMono*) had 8 pairs. It is to be noted that both plants had 16 chromosomes, a result of the presence of 16 chromosomes in the *Mono* parent. Why there should have been 16 chromosomes in the hybrids, rather than 15, as one would have expected, is not yet clear. A fuller discussion of the cytological behavior of *Mono* and its hybrids will be reserved for another paper.

1932:79 *Oe.* ("*Hall 34*" × "*Devil's Gate*") (1931:67, pl. 7 × 1931: 3, pl. 7).

Seed germination 53 per cent (100 seed); only 6 plants survived to be transferred to the field.

Plants were almost as small as *Hall 34* (up to 70 cm.), and showed the appressed marginal hairs of the *Devil's Gate* parent. Buds were moderately colored, the sepal tips long, delicate and somewhat bowed. Other characters were common to the parents, and therefore present in the hybrids.

Chromosome Configuration.—Five plants were examined, and all showed ⊙ 4, 5 pairs. Since the alpha complex of *Hall 34* gives 7 pairs with *ʰhookeri*, it would be expected to give ⊙ 4 with *ʰDevil's Gate*. The beta complex of *Hall 34* is not definitely known in its end arrangement, but there is a possibility, since it gives ⊙ 6 with *ʰhookeri*, that it too may give ⊙ 4 with *ʰDevil's Gate*. There is therefore the possibility that both of the arrangements of ends found in *Hall 34* were represented among the plants studied cytologically.

1932:82 *Oe.* ("*Hall 34*" × *hookeri deV.*) (1931:67, pl. 7 × 1931: 57, pl. 12).

Seed germination 68 per cent (100 seed); 29 plants transferred to field.

This culture was essentially uniform. The parents differed chiefly in breadth and flatness of leaves, color of midrib, and shape of bud. The F_1 plants had leaves intermediate in width, and somewhat crinkly-wavy, with midribs slightly reddened. Buds had long, delicate sepal tips, often distinctly bowed in the middle.

Chromosome Configurations.—Three plants were examined. Of these, 2 plants (α *Hall 34.ʰhookeri*) had 7 pairs, and 1 plant (β *Hall 34.ʰhookeri*) had ⊙ 6. Since the *Hall 34* parent itself had ⊙ 6, it was natural to expect, when α *Hall 34* gave 7 pairs with *ʰhookeri*, that β *Hall 34.ʰhookeri* would have ⊙ 6.

1932:78 *Oe.* ("*Hall 34*" × "*Mateo*") (1931:67, pl. 7 × 1931:4, pl. 15).

Seed germination 39 per cent (100 seed); 30 plants transferred to field, of which all but 4 remained as rosettes.

All plants were low, without central shoots. One plant was clearly of the dwarf type (35 cm. high), one was definitely of the elongate type (60 cm. high); the other two were short, but had the narrow tips of the elongate type, and were probably poorly developed specimens of the latter. There was thus evidence of the splitting in habit so characteristic of *Mateo* and its hybrids. *Mateo* influence was also seen in the rather broad leaves with slight traces of pink in midribs, and appressed marginal hairs. Influence of *Hall 34* was especially noticeable in the rather long sepal tips, much bowed in some buds. Other external characters of the hybrids were common to both parents.

Chromosome Configuration.—Three plants were studied, including the typically dwarf and elongate specimens. All 3 showed ⊙ 4, 5 pairs. As pointed out above (*Hall 34* × *Devil's Gate*), α *Hall 34* must give ⊙ 4 with the arrangement of ends possessed by both *ʰDevil's Gate* and *ʰMateo;* and there is a possibility that β *Hall 34* must also give this configuration. Which of these complexes was present in the 3 plants studied, or whether both were represented, cannot be determined.

1932:83 *Oe.* ("*Hall 34*" × "*Mono*") (1931:67, pl. 7 × 1931:5, pl. 10 [8 prs.]).

Seed germination 26 per cent (100 seed); 17 plants transferred to field.

Plants low, mostly lacking central shoots, the rosette branches spreading widely, thus resembling *Hall 34* in habit. The influence of *Mono* was seen in particular in the flat, thickish leaves, varying in width, and having reddish midribs and appressed marginal hairs. In having long, delicate, somewhat bowed sepal tips, they showed the *Hall 34* influence. Other external characters of the hybrids were typical of both parents.

Chromosome Configuration.—The *Mono* plant used as parent in this cross had 7 pairs of normal chromosomes, plus an extra pair of half-sized chromosomes. One would expect therefore that the hybrids would have 14 normal chromosomes and a single half-sized chromosome. In common with most other crosses so far made using this extra-chromosome *Mono* plant, however, the hybrids have uniformly shown 2 extra half-sized chromosomes. Four plants of this particular cross were examined, and all showed ⊙ 4, 6 pairs, one of the pairs being composed of half-sized chromosomes.

Since the normal chromosomes of *Mono* have the same end arrangement as the chromosomes of *Mateo*, it is to be expected that at least the alpha complex of *Hall 34* would show ⊙ 4 with *Mono*, and there is the possibility that β *Hall 34* also gives the same con-

figuration. Whether α or β *Hall 34*, or both, are represented in the 4 plants examined cannot be determined.

1932:58 *Oe.* ("*Heusi*" × "*Devil's Gate*") (1931:69, pl. 8 (⊙ 4) × 1931: 1, pl. 7).

Seed germination 52 per cent (100 seed); 30 plants transferred to field. Plants up to 1 m. in height, mostly without central shoots, and with erect rosette branches.

The *Heusi* and *Devil's Gate* parents differed chiefly in the amount of coloration of stems, bracts and cones, the *Heusi* plant having less coloration on the stems, but somewhat more on bracts and cones than the *Devil's Gate* plant. The hybrids showed variation in stem color, the *Devil's Gate* parent having been heterozygous for this character; and also presented varying amounts of cone and bract color, for which character both parents were probably heterozygous. Apart from these differences, the parent plants were quite similar, and their characters were reproduced in the hybrids.

Chromosome Configurations.—The *Heusi* plant used in this cross had ⊙ 4, 5 pairs. Three F_1 plants were examined. Two of them (β *Heusi.*[h]*Devil's Gate*) showed ⊙ 4, 5 pairs; one plant (α *Heusi.* [h]*Devil's Gate*) had 7 pairs.

1932:62 *Oe.* ("*Heusi*" × "*Hall 21*") (1931:69, pl. 8 (⊙ 4) × 1931: 65, pl. 6).

Seed germination 74 per cent (35 seed); 15 plants transferred to field, 6 of which remained as rosettes.

Plants resembled *Hall 21* in habit, and in most characters not shared by the parents, but with more prolific branching, less compact, though still quite Hall-like inflorescences, and appressed marginal hairs. Ill-defined variation was observed in width and crinkling of leaves (as seen in other *Hall 21* hybrids). Rather clear-cut segregation was seen in bract and cone color, as observed in both parent cultures (4 with little color, 5 with strong color).

Chromosome Configurations.—The *Heusi* parent had ⊙ 4, 5 pairs, the *Hall 21* parent had 7 pairs. Of 3 F_1 plants examined. 2 plants (α *Heusi.*[h]*Hall 21*) had 7 pairs, and 1 plant (β *Heusi.*[h]*Hall 21*) had ⊙ 4, 5 pairs.

1932:59 *Oe.* ("*Heusi*" × "*Hall 30*") (1931:69, pl. 9 (⊙ 4, ⊙ 4) × 1931:66, pl. 1).

Seed germination 84 per cent (100 seed); 30 plants transferred to field.

A different plant of *Heusi* was used in this cross from that used in the 2 previous crosses, differing principally in the possession of more slender buds and deeper cone and bract color. The hybrids

resembled *Hall 30* in habit (140 cm. high), and had floral tips of the *Hall 30* type, though somewhat more open. The culture showed deep pigmentation of bract and cone, like the female parent, and considerable reddening of the stem. All plants showed marginal coloration of the leaves, although in varying degree, and there was considerable variation in other foliage characters, although on the whole, they tended to resemble the *Hall 30* parent. A clear-cut segregation in marginal hair position was found (15 appressed, 15 erect), showing that the *Heusi* parent had been heterozygous for this character. In other particulars, the hybrids were uniform, and in agreement with both parents.

Chromosome Configurations.—The *Hall 30* parent had ⊙ 4, its genoms being designated α and β *Hall 30*; the *Heusi* parent had 2 ⊙s 4, differing from the plant used in other crosses by having an extra circle. This plant should have been capable of producing germ cells with 4 different arrangements of ends. Six plants were studied, and 3 different configurations noted. One plant had ⊙ 4, 5 pairs; 3 plants had 2 ⊙s 4, 3 pairs; and 2 plants had ⊙ 4, ⊙ 6, 2 pairs. All of these configurations were to be expected in view of what can be determined with respect to the arrangements of ends in the various genoms of this plant of *Heusi*. For a fuller discussion, see p. 424 (see also table 2).

1932:63 *Oe.* ("*Heusi*" × "*Hall 34*") (1931:69, pl. 9 (2 ⊙s 4) × 1931:67, pl. 7).

Seed germination 45 per cent (100 seed); 30 plants transferred to field.

Plants low (80 cm.), without central shoots, the rosette branches spreading rather widely. Except for vague differences in habit, foliage and inflorescence, little evidence of variation was seen. Hybrids had the appressed marginal hairs of *Heusi*, and showed occasional traces of the bowing of sepal tips characteristic of *Hall 34*.

Chromosome Configurations —The *Hall 34* parent had ⊙ 6. One of its genoms (α) had the end arrangement of *ʰhookeri* (giving 7 pairs with it—see p. 373); the end arrangement of the β genom is not known definitely. Since α *Hall 34* is identical with *ʰhookeri* in segmental arrangement, it should give the following configurations with the *Heusi* genom:—with α *Heusi*, ⊙ 4; with β *Heusi*, ⊙ 4, ⊙ 4; with γ *Heusi*, ⊙ 4, ⊙ 6; with δ *Heusi*, ⊙ 6 (for reasoning, see p. 424). Whether β *Hall 34* is capable of giving any of these configurations with one or more of the *Heusi* genoms is unknown.

Of the various possibilities, but 2 were actually realized in the plants studied, namely, ⊙ 4, 5 pairs (in 5 plants), and ⊙ 4, ⊙ 4, 3 pairs (in 4 plants). The preponderance of these, and the absence of

configurations not listed above, suggest the possibility that β *Hall 34* also gives these configurations with certain of the *Heusi* genoms.

1932:57 *Oe.* ("*Heusi*" × "*Mateo*") (1931:69, pl. 8 (⊙ 4) × 1931: 4, pl. 15).

Seed germination 42 per cent (100 seed); 30 plants transferred to field, of which 27 bloomed.

Plants low, showing the distinction into dwarf and elongate types characteristic of hybrids of *Mateo*. Apart from this distinction, and an ill-defined variation in breadth and crinkling of leaves, the plants were uniform, with little stem color except at the tips, with red papillae, strong bract and cone color, buds intermediate in shape, and long fruits.

Chromosome Configurations.—Three plants were examined. Two had 7 pairs (α *Heusi*.ʰ*Mateo*), the third had ⊙ 4 (β *Heusi*.ʰ*Mateo*). These are the only configurations normally possible in this cross, and were predictable on the basis of other information with regard to the composition of *Heusi*.

1932:56 *Oe.* ("*Heusi*" × "*Mono*") (1931:69, pl. 9 (⊙ 4, ⊙ 4) × 1931:5, pl. 6 [⊙ 4]).

Seed germination 89 per cent (100 seed); 29 plants transferred to field.

Plants up to 90 cm. tall, resembling *Mono* in most particulars, and especially in habit, and in delicacy of stems, strong development of stem, bract and cone coloration, color of midribs and leaf margins, and character of flowering tip. Some variation in leaf breadth, amount of crinkling and intensity of marginal color was observed.

Chromosome Configurations.—The plant of *Mono* used in this cross had ⊙ 4, 5 pairs. It is probable that one of its genoms (α *Mono*) was identical in segmental arrangement with the genom produced by the one of its sibs which had 7 pairs of normal chromosomes, plus a pair of diminutives (except for the absence of extra chromosomes). In this case, its segmental arrangement would be the same as that of ʰ*Mateo*, ʰ*Devil's Gate*, etc., and the configurations which it should give with the various genoms of *Heusi* would be as follows: α *Heusi*.α *Mono* = 7 pairs; β *Heusi*.α *Mono* = ⊙ 4: γ *Heusi*.α *Mono* = ⊙ 4, ⊙ 4; δ *Heusi*.α *Mono* = ⊙ 4. The configurations which *Heusi* would give with β *Mono* are unknown, inasmuch as the composition of β *Mono* has not been determined. There is at least a possibility, however, that β *Mono* would give certain of the above configurations with *Heusi*.

Ten plants were examined; one had 7 pairs, 3 had ⊙ 4, and 6 had ⊙ 4, ⊙ 4. The preponderance of ⊙ 4, ⊙ 4 and ⊙ 4 suggests that

some of the genoms of *Heusi* yield these configurations with *♂ Mono*, which is therefore represented among the plants examined.

1931:16 *Oe.* (*hookeri* × "*Johansen*") (1930:9, pl. 8 × 1930:10, pl. 3).

Seed germination 84 per cent (50 seed); 15 plants transferred to field.

Plants 80 cm. high, without central shoots. They resembled *hookeri* in foliage characters, the leaves being narrow, flat, and dark grey-green; in color of bracts; in shape of the floral tips. They were intermediate between the parents in stem color, in cone color and in bud shape. Pigmentation of the midribs was lacking, as in *Johansen*. In general, the appearance was that of a robust *hookeri* with lighter anthocyan pigmentation and longer, more slender buds.

Chromosome Configuration.—Three plants were examined cytologically, all of which had ⊙ 4, 5 pairs.

1931:50 *Oe.* ("*Johansen*" × *hookeri*) (1930:10, pl. 6 × 1930:9, pl. 8).

Seed germination 100 per cent (50 seed); 15 plants transferred to field.

This culture was in every way identical with its reciprocal.

1932:52 *Oe.* ("*Mateo*" × "*Devil's Gate*") (1931:4, pl. 15 × 1931:3, pl. 7).

Seed germination 92 per cent (100 seed); 30 plants transferred to field, of which 10 remained as rosettes.

Plants showed segregation in respect to growth habit, there being 7 dwarfs (up to 73 cm.) and 13 elongate plants (up to 115 cm.). The differences between these were identical with those previously described. Apart from this distinction, the plants were on the whole uniform and intermediate between the parents.

Chromosome Configuration.—Three plants were examined, all of which showed 7 pairs.

1932:55 *Oe.* ("*Mateo*" × *hookeri*) (1931:4, pl. 15 × 1931:57, pl. 12).

Seed germination 27 per cent (100 seed); 18 plants transferred to field.

The plants approached *hookeri* more closely than *Mateo* in leaf width. In pigmentation characters, they were on the whole intermediate, in cases where the parents showed significant differences. On the whole, plants of the elongate type resembled *hookeri*, while the dwarf type bore a close resemblance to *Mateo*. Marginal hairs were appressed in all. There were 7 dwarfs (45 cm.) and 10 elongate plants (90 cm.) (Figs. 7, 8).

FIGS. 7, 8. *Oenothera* ("Mateo" × hookeri), showing segregation into dwarf (Fig. 7) and elongate (Fig. 8) types.

Chromosome Configuration.—Three plants were examined, and all showed ⊙ 4, 5 pairs.

1932:54 *Oe.* ("*Mateo*" × "*Mono*") (1931:4, pl. 15 × 1931:5, pl. 10 [8 pairs]).

Seed germination 77 per cent (100 seed); 30 plants transferred to field, of which 3 remained as rosettes.

The chief differences between the parents were matters of growth form, and of bud shape and hairiness. Most plants had central shoots. The dwarfs (12 plants, height 45 cm.) closely resembled *Mateo;* the elongate plants (15 plants, height 85 cm.) were close to *Mono* in appearance. Buds were intermediate in shape and hairiness. Other characters were common to the parents.

Chromosome Configuration.—Two plants were examined. Both had 7 pairs of normal chromosomes, plus one extra *pair* of half-sized chromosomes, thus fully resembling the pollen parent (cp. pp. 372 and 374).

1933:21 *Oe.* ("*Mono*" × "*Mateo*") (1931:5, pl. 10 (8 pairs) × 1931:4, pl. 15).

Seed germination 85 per cent (100 seed); 30 plants transferred to field.

This culture resembled in every way its reciprocal, there being
17 plants of the elongate type and 8 of the dwarf. The other 5
plants remained as rosettes.

Chromosome Configurations.—An interesting cytological situa-
tion was found in this culture. Three plants were examined. One
of these showed consistently 7 pairs of normal chromosomes and
one pair of diminutive chromosomes. A second plant had 8 pairs
(7 normal, 1 diminutive) in one bud, but 7 pairs minus the diminu-
tives in another bud. The third plant showed in different loculi
of the same bud a variation, some loculi having 7 pairs of normal
chromosomes without diminutives, some having one small chromo-
some, and others having a pair of small chromosomes. It is clear
that, were it not for the extra diminutives in the *Mono* parent,
the configurations of all plants in this F₁ would have been 7 pairs.

1933:22 *Oe.* ("*Mono*" × *hookeri*) (1931:5, pl. 6 (⊙ 4) × 1931:57,
       pl. 12).

Seed germination 63 per cent (100 seed); 30 plants transferred
to field.

Plants 90 cm. high, without central shoots, and with widely
spreading laterals. In general appearance, the plants were *hookeri*-
like. The leaves, however, were somewhat broader than those of
hookeri, and had appressed marginal hairs; moreover, the flowering
tips were somewhat narrower than those of *hookeri*, and the buds
had somewhat longer sepal teeth, tending to bulge in the middle.
Other external features of the hybrids were characteristic of both
parents.

Chromosome Configuration.—All 3 plants examined showed ⊙ 4,
5 pairs. It is not likely that both of the end arrangements found
in the *Mono* parent are represented among these plants, for the
chances of α and β *Mono* having arrangements which will give ⊙ 4
with each other, at the same time that both give ⊙ 4 with *ʰhookeri*,
are enormously small. In fact, the only conditions under which
these configurations will all be realizable are where the same 2
chromosomes, but different ends, are involved in the interchanges
producing α and β *Mono; e.g.*, if *ʰhookeri* has 7·8 9·10, and α *Mono*
has 7·10 9·8, then β *Mono* has 7·9 10·8. No other type of inter-
change will give a triangle of end arrangements, each of which gives
⊙ 4 with each of the others.

1933:23 *Oe.* ("*Mono*" × "*Johansen*") (1931:5, pl. 10 (8 pairs) ×
       1931:2, pl. 9).

Seed germination 99 per cent (100 seed); 30 plants transferred
to field.

Plants 110 cm. high, mostly without central shoots, the rosette
branches erect and numerous. In general appearance, the plants

were like *Johansen*, but were more vigorous, had darker foliage, appressed marginal hairs, pinkish midribs, narrower, more cylindrical floral tips, and were intermediate in bud shape and in the amount of pigmentation of stems, bracts and buds.

Chromosome Configuration.—Eight plants were examined cytologically. All had 8 pairs (7 pairs of normal chromosomes, and one extra pair of diminutive chromosomes).

C. F_1 Hybrids Between California Races and Races from Outside California

A number of hybrids involving on the one hand *hookeri* and *franciscana*, and on the other hand races from outside California, have been previously described by various authors, and will not be discussed here. The chromosome configurations of these hybrids, however, are listed, together with those of the hybrids described in the present paper, in table 3.

1931:31 *Oe.* (*chicaginensis* × *"Dalton"*) (1930:18, pl. 1 × 1930: 11, pl. 2).

Seed germination 100 per cent (50 seed); 15 plants transferred to field. There were 14 with the composition *excellens.^{h}Dalton*, and 1 metacline with the composition *punctulans.^{h}Dalton*.

excellens.^{h}Dalton.—Plants showed the influence of *excellens* in habit, being bushy, with strong central shoots (1 m. high) and suberect rosette branches. *Excellens* was also in evidence in the following features: crinkling of leaves, red flecks on young rosette leaves, red midribs, green leaf margins, appressed marginal hairs, reduced flowers, short styles and short fruits. The influence of ^{h}*Dalton* was seen in a narrowing of the leaves and floral tips (in both respects intermediate between parents), in the presence of red papillae and greatly enlarged hair bases on bud-cones. On the whole, the influence of *excellens* was predominant, with ^{h}*Dalton* modifying it in only a few particulars.

punctulans.^{h}Dalton.—*Punctulans* was equally dominant in its effect on the hybrid, asserting itself in the strict habit (plants tall and slender [120 cm.], with central shoots and numerous erect rosette branches); thickened greyish-green stems, with reduced basal color, and with the long hairs (and consequently the red papillae) reduced in number and size; light greyish-green, thickish, elongate leaves; stout, thick-walled buds, shortened styles; reduced flower size, and greyish fruits. The presence of ^{h}*Dalton* was best shown by the slight reddening of the stem, and the horizontal position of the long bud pubescence.

Chromosome Configurations.—Three plants of *excellens.^{h}Dalton*

TABLE 3

CHROMOSOME CONFIGURATIONS OF F_1 HYBRIDS BETWEEN CALIFORNIA RACES AND
RACES FROM OUTSIDE CALIFORNIA

Cross	Complex-combination	Chromosome-configuration
biennis × *hookeri*	*albicans.*ʰ*hcok.*	○ 14 (Cleland, 1928)
	*rubens.*ʰ*hcok.*	○ 10 (Cleland, 1928)
chicaginensis × *Dalton*..........	*excellens.*ʰ*Dal.*	7 pairs (3 pls.)
	*punctulans.*ʰ*Dal.* (meta-cline)	⊙ 12 (1 pl.)
chicaginensis × *Devil's Gate* ...	*excellens.*ʰ*Dev. G.*	7 pairs (3 pls.)
chicaginensis × *hookeri*..........	*excellens.*ʰ*hook.*	⊙ 4 (Renner & Cleland 1933)
chicaginensis × *Johansen*	*excellens.*ʰ*Joh.*	7 pairs (3 pls.)
cockerelli × *hookeri*	*curtans.*ʰ*hook.*	⊙ 10 (3 pls.)
	*elongans.*ʰ*hook.* (metacline)	○ 4, ⊙ 8 (1 pl.)
cockerelli × *Johansen*..........	*curtans.*ʰ*Joh.*	○ 4, ⊙ 6 (3 pls.)
Dalton × *r-lamarckiana*..........	ʰ*Dalt.velans*	⊙ 6 (2 pls.)
	ʰ*Dalt.gaudens*	⊙ 10 (2 pls.)
Devil's Gate × *grandiflora* ...	ʰ*Dev.G.truncans*	○ 14 (1 pl.)
Devil's Gate × *r-lamarckiana*...	ʰ*Dev.G.velans*	⊙ 6 (1 pl.)
	ʰ*Dev.G.gaudens*	? (1 pl.)
franciscana E & S × *cockerelli*	ʰ*franc.elongans*	3 ⊙s 4 (Emerson & Sturtevant 1931)
franciscana de V. × *r-lamarck.*	ʰ*franc.velans*	⊙ 4 (Cleland, 1932)
franciscana Sh. × *r-lamarck.*...	ʰ*franc.velans*	⊙ 4 (Cleland, 1932)
grandiflora × *Dalton* ...	*acuens.*ʰ*Dal.*	⊙ 4 (3 pls.)
	*truncans.*ʰ*Dal.*	⊙ 14 (2 pls.)
grandiflora × *Devil's Gate*	*acuens.*ʰ*Dev.G.*	○ 4 (3 pls.)
	*truncans.*ʰ*Dev.G.*	⊙ 14 (2 pls.)
grandiflora × *franciscana de V.*	*acuens.*ʰ*franc.*	2 ⊙s 4 (3 pls.)
	*truncans.*ʰ*franc.*	⊙ 14 (3 pls.)
grandiflora × *hookeri*..........	*acuens.*ʰ*hook.*	2 ⊙s 4 (Cleland & Oehlkers 1929)
	*truncans.*ʰ*hook.*	⊙ 14 (Cleland & Oehlkers 1929)
grandiflora × *Johansen* ...	*acuens.*ʰ*Joh.*	⊙ 4 (3 pls.)
	*truncans.*ʰ*Joh.*	⊙ 14 (3 pls.)
Hall 30 × *r-lamarckiana*. ...	3 *Hall 30.velans*	○ 6 (1 pl.)
	α *Hall 30.velans*	⊙ 4 (4 pls.)
Hall 30 × *grandiflora* .	α or β *Hall 30.truncans*	⊙ 14 (2 pls.)
Heusi (⊙ 4) × *grandiflora*	α *Heusi acuens*	○ 4 (1 pl.)
	β *Heusi velans*	7 pairs (1 pl.)
	α or β *Heusi truncans*	⊙ 14 (2 pls.)

TABLE 3—*Continued*

Cross	Complex-combination	Chromosome-configuration
Heusi (⊙ 4) × *r-lamarckiana*	α*Heusi.velans*	⊙ 6 (1 pl.)
	β *Heusi.velans*	○ 4, ○ 6 (1 pl.)
hookeri × *chicaginensis*.........	ᵏ*hook.punctulans*	⊙ 10 (Renner & Cleland 1933)
hookeri × *cockerelli*.........	ᵏ*hook.elongans*	○ 4, ⊙ 8 (1 pl.)
hookeri × *grandiflora*........	ᵏ*hook.acuens*	2 ⊙s 4 (Cleland & Oehlkers 1929)
	ᵏ*hook.truncans*	○ 14 (Cleland & Oehlkers 1929)
hookeri × *r-lamarckiana* .	ᵏ*hook.velans*	○ 4 (Cleland & Blakeslee 1931)
hookeri × *suaveolens*.........	ᵏ*hook.flavens*	⊙ 4 (Cleland & Blakeslee 1931)
Johansen × *chicaginensis*	ᵏ*Joh.punctulans*	⊙ 12 (1 pl.)
Johansen × *grandiflora*	ᵏ*Joh.truncans*	⊙ 14 (2 pls.)
Johansen × *r-lamarckiana*	ᵏ*Joh.velans*	⊙ 6 (2 pls.)
r-lamarckiana × *Dalton*........	*velans.*ᵏ*Dalt.*	⊙ 6 (2 pls.)
	*gaudens.*ᵏ*Dalt.*	⊙ 10 (3 pls.)
r-lamarckiana × *Devil's Gate* ..	*velans.*ᵏ*Dev.G.*	⊙ 6 (1 pl.)
	*gaudens.*ᵏ*Dev.G.*	⊙ 10 (3 pls.)
r-lamarckiana × *franciscana de V.*	*velans.*ᵏ*franc.*	⊙ 4 (Cleland 1932)
	*gaudens.*ᵏ*franc.*	⊙ 10 (Cleland 1932)
r-lamarckiana × *hookeri*........	*velens.*ᵏ*hook.*	⊙ 4 (Cleland & Blakeslee 1931)
	*gaudens.*ᵏ*hook.*	⊙ 10 (Cleland & Blakeslee 1931)
r-lamarckiana × *Johansen*.....	*velans.*ᵏ*Joh.*	⊙ 6 (2 pls.)
	*gaudens.*ᵏ*Joh.*	⊙ 10 (3 pls.)
Mateo (pl. 4) × *shulliana*.......	ᵏ*Mat.(?).maculans*	⊙ 8 (2 pls.)
muricata × *Dalton*...........	*rigens.*ᵏ*Dalt.*	⊙ 8 (2 pls.)
	*curvans.*ᵏ*Dalt.* (*metacline*)	⊙ 4, ⊙ 8 (1 pl.)
muricata × *Devil's Gate.*	*rigens.*ᵏ*Dev.G.*	⊙ 8 (4 pls.)
muricata × *franciscana de V.*.....	*rigens.*ᵏ*franc.*	⊙ 6 (Cleland 1932)
muricata × *franciscana Sh.*.....	*rigens.*ᵏ*franc.*	⊙ 6 (Cleland 1932)
	*curvans.*ᵏ*franc.* (*metacline*)	⊙ 6, ⊙ 8 (Cleland, (1932)
muricata × *hookeri*...........	*rigens.*ᵏ*hook.*	⊙ 6 (Cleland, 1932)
	*curvans.*ᵏ*hook.* (*metacline*)	⊙ 6, ⊙ 8 (Cleland, 1932)
muricata × *Johansen*..........	*rigens.*ᵏ*Joh.*	⊙ 8 (3 pls.)
	*curvans.*ᵏ*Joh.* (*metacline*)	⊙ 4, ⊙ 8 (1 pl.)
nobska × *hookeri*.............	*pubens.*ᵏ*hook.*	⊙ 12 (Sturtevant 1931)

TABLE 3—*Continued*

Cross	Complex-combination	Chromosome-configuration	
nobska × *Mateo* (pl. 10) ...	*pubens*.α or β *Mateo*	○ 12	(4 pls.)
oakesiana × *Mateo* (pl. 10) ...	*accelerans*.α or β *Mateo*	○ 12	(4 pls.)
oakesiana × *Mono* (8 prs.) ...	*accelerans*.ʰ*Mono*	○ 12, 2 prs.(2 pls.)	
ostreae × *Johansen*...... ...	*fascians*.ʰ*Johansen*	○ 8	(3 pls.)
shulliana × "*sulfur dwarf*" (= *sd-franciscana*)	*jugens*.*sd*-ʰ*franc*.	○ 10 (Sturtevant 1931)	
shulliana × *Mateo* (pl. 10)	*jugens*.α or β *Mateo*	○ 12	(1 pl.)
		○ 10	(1 pl.)
	maculars.α or β *Mateo*	○ 10	(2 pls.)
suaveolens × *Dalton*	*albicans*.ʰ*Dalt*.	○ 12	(3 pls.)
	flavens.ʰ*Dalt*.	2 ○s 4	(2 pls.)
suaveolens × *Devil's Gate*... ...	*albicans*.ʰ*Dev.G*.	○ 12	(3 pls.)
	flavens.ʰ*Dev.G*.	2 ○s 4	(3 pls.)
suaveolens × *franciscana* Sʰ.....	*albicans*.ʰ*franc*.	○ 14 (Cleland 1932)	
	flavens.ʰ*franc*.	○ 4 (Cleland, 1932)	
suaveolens × *Johansen*........	*albicans*.ʰ*Joh*.	○ 12	(3 pls.)
	flavens.ʰ*Joh*.	2 ○s 4	(3 pls.)

had 7 pairs. *Excellens* is thus seen to have the same arrangement of end segments as that most frequently found in California forms. The *punctulans*.ʰ*Dalton* plant had ⊙ 12, 1 pair. This is the expected configuration, inasmuch as *excellens*.*punctulans* has ⊙ 12, and ʰ*Dalton* has the same end arrangement as *excellens*.

Pollen Counts.—(*excellens*.ʰ*Dalton*, 1 pl.) good 210, inactive 20, empty 527. Total 757. (*punctulans*.ʰ*Dalton*, 1 pl.) good 260, inactive 48, empty 1030. Total 1338.

1931:32 *Oe.* (*chicaginensis* × "*Devil's Gate*") (1930:18, pl. 1 × 1930:12, pl. 11).

Seed germination 84 per cent (50 seed); 15 plants transferred to field.

In habit, plants were typical *excelsae*, with tall central shoots (115 cm.) and rather spreading rosette branches. *Excellens* characteristics included: brilliant basal coloration of stems, slight crinkling and absence of waviness in foliage, bright red midribs, red flecks, broad, many-flowered floral tips, sparse and spreading pubescence on buds. ʰ*Devil's Gate* showed its influence in the presence of red papillae, and of splashes of red on the bud-cones. In style length, flower size and fruit length, the conflicting effects of the two complexes were more or less evenly balanced, giving intermediate

conditions. Both complexes contributed in this case green stem
tips (a different plant of *Devil's Gate* was used in this cross from the
one used to continue the race), appressed marginal hairs and broad,
dark green leaves.

Chromosome Configuration.—Three plants were examined cyto-
logically, and all showed 7 pairs. In view of the presence of 7 pairs
in *excellens*.[h]*Dalton*, this was the expected configuration in this com-
bination.

Pollen Count (1 pl.).—Good 231, inactive 31, empty 962. Total
1224.

1931:30 *Oe. (chicaginensis* × *"Johansen")* (1930:18, pl. 1 × 1930:
10, pl. 2).

Seed germination 90 per cent (50 seed); 15 plants transferred
to field.

Culture uniform, the complex-combination being *excellens*.[h]*Jo-
hansen.* *Excellens* contributed markedly to general habit, with cen-
tral shoots (120 cm. high), and numerous suberect rosette branches.
It also produced a deep basal stem color and clear green, somewhat
crinkled foliage with brown flecks in the young rosettes, and ap-
pressed marginal hairs; it caused the bracts to remain erect in the
young tips, without flaring, and increased the number of buds found
in a tip; it reduced the size of flowers and length of fruits. [h]*Johan-
sen* contributed red color to the stem tips, reddening of the under
side of the bracts, a uniform, though light, pigmentation of the bud
cones, long styles, occasional red stripes on the young fruits, and
large leaves, including bracts. The floral tips were large, but not
so large as in *Johansen*, and stricter. The buds were considerably
shorter than in *Johansen*, stouter, and had sepal tips of moderate
length. On the whole, the hybrids presented a decided mosaic of
characters attributable to the two complexes.

Chromosome Configuration.—The 3 plants examined showed 7
pairs, as was to be expected, since [h]*Johansen* has the same end ar-
rangement as [h]*Dalton* and [h]*Devil's Gate*.

Pollen Count (1 pl.).—Good 258, inactive 9, empty 613. Total
880.

1932:45 *Oe. ("Johansen"* × *chicaginensis)* (1930:10, pl. 6 × 1930:
18, pl. 1).

Seed germination 92 per cent (100 seed); 15 plants transferred
to field.

Culture uniform, the complex-combination being [h]*Johansen.
punctulans.* *Punctulans* was responsible for the tall, rather strict
habit (central shoots 120 cm. high); gave to stems, leaves and fruits
a grey-hoary caste, caused narrowing and waviness of foliage, ap-

pressed marginal hairs, reduced length of hirsute pubescence on the buds and caused it to lie forward, and reduced petal size. [h]*Johansen* imparted to stems a moderate amount of pigmentation, both at the base and at the extreme tips; gave to the midribs a faint flush of color, colored leaf margins slightly in young leaves, lengthened bracts and gave to them a slight tinge of red underneath; imparted a weak pigmentation to bud-cones, and lengthened the styles. Red papillae were contributed by both complexes. In general, the plants were *punctulatae* in habit, and in the chief foliage characters; approached *Johansen* in pigmentation factors, and had floral tips of an intermediate character.

Chromosome Configuration.—The only plant examined had $\odot$ 12, 1 pair. This was predictable, since '*Johansen* has the same segmental arrangement as *excellens*, which gives $\odot$ 12 with *punctulans*.

1932: 39 *Oe. (cockerelli* $\times$ *hookeri)* (1930: 7. pl. 1 $\times$ 1930: 9, pl. 1).

This cross and its reciprocal were first described by de Vries (1913), and later by Oehlkers (1921). In order to obtain chromosome configurations, the crosses were repeated by the writer, and the F_1 grown in 1932. Since the original descriptions were rather meager, and in some respects in disagreement with my findings, brief characterizations are given herewith.

Seed germination 51 per cent (100 seed); 15 plants transferred to field.

Two plants were metaclines (*elongans*.[h]*hookeri)*. The rest were *curtans*.[h]*hookeri.* Both phenotypically and cytologically the metaclines were like their reciprocals. The formation of metaclines by *cockerelli* has been reported by Oehlkers in *Oe. (cockerelli* $\times$ *strigosa)* (1926).

curtans.[h]*hookeri.*—Culture uniform, plants 80 cm. high, with or without central shoots, the rosette branches spreading rather widely. The phenotypic effect of [h]*hookeri* was modified by *curtans* as follows: basal stem coloration reduced to a minimum, leaves broadened slightly, midrib color reduced to a mere trace, marginal hairs appressed; bracts made to flare widely, red pigmentation on the underside of the bracts eliminated; buds made more slender, with longer sepal tips, the styles shortened until the stigma is touched by the anthers; flower size reduced and fruits shortened. Marginal color of the leaves, as produced by [h]*hookeri*, was retained, and the red papillae and red stem tips characteristic of both complexes were present.

elongans.[h]*hookeri.*—The 2 plants of this composition resembled exactly their reciprocals (*vide infra*).

Chromosome Configurations.—Three plants of *curtans*.[h]*hookeri* had $\odot$ 10, 2 pairs; one of the metaclines had $\odot$ 4, $\odot$ 8, 1 pair.

1932: 38 *Oe. (hookeri* × *cockerelli*) (1930: 9, pl. 11 × 1930: 7, pl. 1).

Seed germination 95 per cent (100 seed); 15 plants transferred to field.

Elongans showed certain modifications in the phenotypic effect of *ʰhookeri,* as follows: it caused rosette branches to lie almost procumbent. reduced basal stem coloration somewhat, almost eliminated stem tip color; broadened leaves and imparted to them a degree of crinkling and waviness, appressed marginal hairs, almost eliminated midrib color; gave to the broadened, wavy bracts a strong flare. and eliminated red pigmentation on the under side; lengthened sepal tips, eliminated cone color completely, shortened pubescence of the buds and caused it to point forward; shortened styles until the stigma was touched by the anthers, and reduced flower size. Marginal leaf coloration and long fruits, characteristics of *hookeri,* were retained. Plants bloomed late in the season.

In comparison with *curtans, elongans* produced with *ʰhookeri* longer stems. procumbent rosette branches. broader, wavier leaves; was less effective in reducing basal stem color, but was able to reduce stem tip color, and completely eliminated cone color. It failed to shorten fruits, and the plants bloomed later.

Chromosome Configuration.—Two plants showed ☉ 4, ☉ 8. 1 pair, in agreement with their reciprocal.

1932: 44 *Oe. (cockerelli* × "*Johansen*") (1930: 7, pl. 11 × 1930: 10, pl. 2).

Seed germination 82 per cent (100 seed); 15 plants transferred to field.

Culture uniform, the plants 85 cm. high, mostly without central shoots, rosette branches erect, tall. *ʰJohansen* contributed light red stem color, light green foliage. marginal color, weak pigmentation on under side of bracts and on bud cones. *Curtans* reduced stem, bract and bud coloration, appressed marginal hairs; reduced style length, so that the stigma touched the anthers; reduced flower size and fruit length. Complexes were opposed in leaf breadth and character of floral tip, producing leaves of intermediate width, and bracts which were somewhat more erect below and more flaring above than in *Johansen.* Complexes were in agreement in producing red papillae and apical stem coloration.

Chromosome Configuration.—Three plants showed ☉ 4, ☉ 6, 2 pairs.

1931: 41 *Oe.* ("*Dalton*" × *grandiflora*) (1930: 11, pl. 2 × 1930: 16, pl. 2).

Seed germination 97.5 per cent (80 seed); 29 plants transferred to field.

Two classes were recognizable from the beginning, one composed of weak and yellowish plants (*'Dalton.acuens*), the other of healthy plants (*[h]Dalton.truncans*). It is evident that *Dalton* plastids are unable to function properly in the presence of the combined *[l]Dalton* and *acuens* genoms.

Of the plants transferred to the field, 16 were *acutae* and 13 *truncatae*. None of the former flowered, and all but 4 died early. The *truncatae* were identical with their reciprocals (for description of *acutae* and *truncatae*, see next pedigree).

No fixations were made from this culture.

1931:24 *Oe. (grandiflora* × *"Dalton")* (1930:16, pl. 1 × 1930:11, pl. 2).

Seed germination 73 per cent (80 seed): 30 plants transferred to field, of which 1 died; 17 were *acutae*, 12 *truncatae*.

acuens.[h]Dalton.—Acuens influence was chiefly seen in the bushy habit (central shoots 120 cm., rosette branches rather spreading), the relative absence of fine felty pubescence on stems (long hairs retained), the rather broad, crinkly, lightish green leaves, with green margins and appressed hairs; the large erect bracts, sparse pubescence on bud-cones, and absence of hypertrophied hair-bases. *[h]Dalton* influence was especially evident in the strong basal stem color, weak apical stem color and numerous red papillae. Both complexes were alike in producing white midribs, bracts and buds free from anthocyan, slender long-tipped buds, horizontal bud pubescence, long styles, large flowers, long fruits.

truncans.[h]Dalton.—Truncans produced the following effects: bushy habit (125 cm. high, rosette branches erect, short), reduction in number of long hairs and papillae on stem (felty pubescence retained), wavy leaves with brown flecks, slightly reddened midribs, green margins and appressed hairs; long flaring bracts, bud pubescence lying somewhat forward. *[h]Dalton* produced a slight reddening of stem tips. Both complexes tended to produce the deep basal stem color, strong felty canescence on stems, narrow leaves, green bracts and buds, long slender buds with long sepal tips, long styles, large flowers, long fruits.

The distinctions between *acutae* and *truncatae* were here very clear. *Acutae* had relatively longer, more spreading rosette branches, less stem color below, broader and lighter green leaves, erect bracts, more slender buds, with spreading and sparse pubescence, *vs.* dense appressed pubescence.

Chromosome Configurations.—Three plants of *acuens.[h]Dalton* were found to have ⊙ 4, 5 pairs. Two plants of *truncans.[h]Dalton* had ⊙ 14.

Pollen Counts.—(acuta, 1 pl.) good 210. inactive 4, empty 40. Total 254. (truncata, 1 pl.) good 212, inactive 5, empty 416. Total 633.

1931:42 *Oe. ("Dalton" × r-lamarckiana)* (1930:11, pl. 2 × 1930: 2, pl. 13).

Seed germination 97.5 per cent (80 seed): 30 plants transferred to field. Twin hybrids were present, [h]*Dalton.velans* (24 plants), and [h]*Dalton.gaudens* (6 plants).

[h]*Dalton.velans.*—Both complexes aided in the production of basal and apical stem color, red papillae. hirsute and felty pubescence, white midribs, spreading bracts, glandular pubescence on buds, long styles and large flowers. *Velans* alone was responsible for the waviness of the leaves, green margins, appressed marginal hairs; red pigmentation on bracts and traces of red on bud cones; stout buds with thick sepal tips, stout fruits. [h]*Dalton* produced narrower leaves than is usual in *velutinae*, and the frequent occurrence of enlarged hair bases on buds.

[h]*Dalton.gaudens.*—The effect of *gaudens* was pre-eminent. *Gaudens* effects were: nearly complete absence of basal stem coloration, absence of fine pubescence on stems; broad, clear green, crinkled and wavy leaves, with white midribs, brown flecks. green margins and appressed marginal hairs; large wavy bracts, forming loose floral tips; buds sparsely hairy, fruits short. [h]*Dalton* influence was seen in the slight traces of red coloration at stem tips, the red papillae, and enlarged hair bases on buds. Both complexes were involved in the absence of anthocyan on bracts and cones, in the presence of long slender buds with long, delicate sepal tips, of long styles and large flowers.

Chromosome Configurations.—Two plants of [h]*Dalton.velans* had ☉ 6, 4 pairs. Two plants of [h]*Dalton.gaudens* had ☉ 10, 2 pairs.

Pollen Count (velutina, 1 pl.).—Good 252, inactive 0, empty 115. Total 367.

1931:34 *Oe. (r-lamarckiana × "Dalton")* (1930:2, pl. 13 × 1930: 11, pl. 2).

Seed germination 32 per cent (150 seed); 15 plants transferred to field, including 6 *velutinae* and 9 *laetae*. In all respects these plants resembled their reciprocals (*vide supra*), even to the color of the foliage.

Chromosome Configurations.—In agreement with their reciprocals, 2 *velutinae* showed ☉ 6, 4 pairs, and 3 *laetae* gave ☉ 10, 2 pairs.

Pollen Count (laeta, 1 pl.).—Good 224, inactive 12, empty 302. Total 538.

1931:40 *Oe.* ("*Dalton*" × *suaveolens*) (1930:11. pl. 2 × 1930:15, pl. 15).

Seed germination 98 per cent (50 seed).

All plants were more or less chlorotic, only one surviving the season, and this failing to bloom. These plants had the composition [h]*Dalton.flavens*. Evidently, *Dalton* plastids are unable to function adequately in the presence of a combination of the [h]*Dalton* and *flavens* genoms. In the reciprocal cross, this complex-combination was a healthy green.

1931:14 *Oe.* (*suaveolens* × "*Dalton*") (1930:15, pl. 15 × 1930:11, pl. 2).

Seed germination 76 per cent (80 seed); 30 plants transferred to field, which included 8 *albatae* and 22 *flavae*.

flavens.[h]*Dalton.*—Plants took their habit and chief foliage characters mainly from *flavens*, their pigmentation characters from [h]*Dalton*. Plants were bushy (120 cm. high), with central shoots. *Flavens* characters were: foliage broad, dark green, flecked, slightly crinkled, not wavy, with green margins and appressed marginal hairs; pubescence of buds reduced in amount. [h]*Dalton* characters were: bright red basal stem color, reddened stem tips (faint), red papillae, long slender buds with long sepal tips, rather long styles (stigma free from anthers), long slender fruits. Characters inherited through both complexes were: white midribs, and green bracts and buds. Flowers were quite large.

albicans.[h]*Dalton.*—Neither *albicans* nor [h]*Dalton* tends strongly toward the production of central shoots, and these were entirely lacking. [h]*Dalton* managed to color stems below and at tip only slightly, but red papillae were abundant. Characters inherited through both complexes were: long narrow leaves, white midribs, greyish stems and foliage, green bracts and buds, long styles. *Albicans* was responsible for green leaf margins, appressed marginal hairs, stout buds with short sepal tips, stoutish and greyish fruits. Flowers were quite large.

Chromosome Configurations.—Two plants of *flavens.*[h]*Dalton* had ⊙ 4, ⊙ 4, 3 pairs. Three plants of *albicans.*[h]*Dalton* showed ⊙ 12, 1 pair.

Pollen Counts.—(flava, 1 pl.) good 234, inactive 65, empty 298. Total 597. (albata, 1 pl.) good 200, inactive 172, empty 754. Total 1126.

1931:48 *Oe.* ("*Devil's Gate*" × *grandiflora*) (1930:12, pl. 9 × 1930:16, pl. 2).

Seed germination 90 per cent (80 seed); 20 plants transferred to field.

The *acutae* were weak and chlorotic. Most died as seedlings, and none survived the season. Apparently, *Devil's Gate* plastids are unable to function satisfactorily in the presence of the combined *ʰDevil's Gate* and *acuens* genoms.

The *truncatae* were identical with their reciprocals (for description, see next pedigree).

Chromosome Configuration.—One plant of *ʰDevil's Gate.truncans* had ⊙ 14.

1931:25 *Oe.* (*grandiflora* × "*Devil's Gate*") (1930:16, pl. 2 × 1930:
12, pl. 11).

Seed germination 95 per cent (80 seed); 30 plants transferred to field (20 *acutae*, 10 *truncatae*).

acuens.ʰDevil's Gate.—In habit, plants were chiefly influenced by *acuens*, being tall, with central shoots. Other *acuens* characters were: light green foliage, erect bracts and loose floral tips. Characters attributable to *ʰDevil's Gate* were bright red basal stem color, red papillae, wavy foliage, light red midribs, irregular splotches of red on buds. Characters common to both complexes were: green stem tips (characteristic of pl. 11 of 1931 culture of *Devil's Gate*, not of pl. 9), green leaf margins, appressed marginal hairs, long slender buds with long tips, long styles, large flowers and long fruits.

truncans.ʰDevil's Gate.—Influence of *truncans* was seen chiefly in habit, central shoots being present, the rosette branches being shorter than in *acutae*. Other *truncans* characters included reduction in number of long hairs and papillae on stems, narrow leaves, brown-tipped bracts, and semi-appressed bud pubescence. *ʰDevil's Gate* influence was seen in patches of red on bud-cones. Both complexes contributed to the vivid basal stem color and green tips; to waviness of foliage, red color in midribs, green margins and appressed marginal hairs; to flaring of the bracts and flatness of floral tips; to making buds long and slender, the styles and fruits long, the flowers large.

Distinctions between *acutae* and *truncatae* were clear and unmistakable, especially just before the onset of flowering (see p. 388).

Chromosome Configurations.—Three plants of *acuens.ʰDevil's Gate* showed ⊙ 4, 5 pairs; 2 plants of *truncans.ʰDevil's Gate* showed ⊙ 14. These configurations were expected, since *ʰDalton*, whose end arrangement is the same as that of *ʰDevil's Gate*, gave the same configurations with *acuens* and *truncans*.

Pollen Counts.—(acuta, 1 pl.) good 274, inactive 50, empty 31. Total 355. (truncata, 1 pl.) good 224, inactive 0, empty 381. Total 605.

1931:49 *Oe.* ("*Devil's Gate*" × *r-lamarckiana*) (1930:12, pl. 9 ×
        1930:2, pl. 13).

Seed germination 49 per cent (69 seed); 26 plants transferred
to field, including 16 *velutinae* and 10 *laetae.*

ʰDevil's Gate.velans.—Plants 110 cm. high, mostly with central
shoots, bushy.   Due to apparent heterozygosity of the *Devil's Gate*
parent, segregation in basal stem color was found (7 strongly col-
ored, 7 lightly colored).   Other characters due chiefly to *ʰDevil's
Gate* were: midribs rather pink, bracts erect in young tip, giving
compact, somewhat elongated floral tips, long fruits.   Characters
due chiefly or wholly to *velans* were: bracts reddened below, bud
cones and hypanthia quite red, buds stout, fruits stout.   Both com-
plexes contributed more or less equally to: general habit, presence
of both long and felty pubescence on stems, red papillae, purplish
stem tips, broad and crinkled leaves with green margins and ap-
pressed marginal hairs, flaring bracts, long styles and large flowers.

ʰDevil's Gate.gaudens.—Plants were light green and rather sickly
as seedlings.   Those which survived, however, outgrew this condi-
tion, and became thriving specimens (4 plants flowered).   At ma-
turity, plants were typical *laetae*, with broad crinkled foliage; broad,
erect, scarcely flaring bracts without red pigmentation; and very
long and slender buds, devoid of pigmentation and sparingly pubes-
cent.   *ʰDevil's Gate* expressed itself in a segregation in respect to
basal stem color (2 plants brilliant red, 2 scarcely reddened); in the
presence of red papillae, occasional traces of midrib color, long
fruits.   Both complexes carried inheritance for broad leaves, with
green margins and appressed marginal hairs; long slender buds, long
styles, large flowers.

Chromosome Configurations.—One plant of *ʰDevil's Gate.velans*
had ☉ 6, 4 pairs.   One plant of *ʰDevil's Gate.gaudens* showed ☉ 4,
☉ 8, 1 pair.   The latter, however, is an aberrant configuration, as
shown by the fact that all other combinations of *gaudens* with com-
plexes having the segmental arrangement of *ʰDevil's Gate* have
shown ☉ 10 (including the reciprocal of this cross).   Since ☉ 4,
☉ 8 cannot be derived from ☉ 10 by a single interchange, it is
probable that a mistake was made in labelling, and that this result
should be discounted.   There were several other pedigrees grown
the same year which had ☉ 4, ☉ 8.

1931:35 *Oe.* (*r-lamarckiana* × "*Devil's Gate*") (1930:2, pl. 13 ×
        1930:12, pl. 9).

Seed germination 66 per cent (80 seed); 30 plants transferred
to field.

There were 8 typical *velutinae* and 14 typical *laetae.*   In addi-

tion, 8 plants (of which only 3 survived), showed various types of abnormality. One or two of these may have been contaminations, the rest were probably zygotes with modified gene complexes.

The typical *velutinae* and *laetae* resembled exactly their reciprocals, even to the color of the foliage. Both showed segregation in respect to stem coloration (3 *velutinae* bright red, 2 dull; 5 *laetae* bright, 9 dull). The *laetae* also showed slight variation in cone and bract color, 4 plants having traces of color (from *hDevil's Gate*), the remainder being green. Apart from these characters, significant variation was not found within classes.

Chromosome Configurations.—One plant of *velans*.*hDevil's Gate* showed ☉ 6, 4 pairs. Three plants of *gaudens*.*hDevil's Gate* had ☉ 10, 2 pairs. These configurations were expected, in view of the fact that combinations of *hDalton* with *velans* and *gaudens* gave the same configurations.

Pollen Counts.—(velutina, 1 pl.) good 274, inactive 2, empty 144. Total 420. (laeta, 1 pl.) good 290, inactive 3, empty 279. Total 572.

1931:47 *Oe.* (*"Devil's Gate"* × *suaveolens*) (1930:12, pl. 9 × 1930: 15, pl. 15).

Seed germination 92 per cent (50 seed). All plants were chlorotic and died as seedlings. *Devil's Gate* plastids, like those of *Dalton*, are unable to function in the presence of the combined *hDevil's Gate* and *flavens* genoms.

1931:15 *Oe.* (*suaveolens* × *"Devil's Gate"*) (1930:15, pl. 15 × 1930: 12, pl. 9).

Seed germination 84 per cent (80 seed); 30 plants transferred to field, of which 19 were *flavae* and 11 *albatae*.

flavens.*hDevil's Gate.* Plants had the bushy habit characteristic of *flavens* hybrids, with central shoots reaching 120 cm. Additional *flavens* characters were: flat leaves, upright bracts in young tip, short style. *Devil's Gate* characteristics were: red stem coloration below and at tips, red papillae, traces of pink in midribs; pigment on under side of bracts on some plants, the cones in these plants having dull red stripes (7 plants in 29 which bloomed); and long, slender buds, quite hairy, with long delicate sepal tips. Both complexes carried inheritance for broad leaves, green leaf margins, and appressed marginal hairs. Flowers were intermediate in size, and fruits had the length characteristic of *Devil's Gate*, together with the stoutness typical of *flavens*.

albicans.*hDevil's Gate.* Since neither *albicans* nor *hDevil's Gate* has a strong tendency toward the development of central shoots, these were absent, or put in a belated appearance in a few cases

(plants 90 cm. high). *Albicans* suppressed basal stem color almost completely, but allowed apical stem color and red papillae; it lengthened, narrowed and thickened the leaves, and gave to the young floral tips an obconical shape. It increased the diameter of the buds, and completely eliminated red coloration in bracts and buds. Both complexes carried factors for greyish-green foliage, green leaf margins, appressed marginal hairs, spreading bracts and long styles. Flowers were intermediate in size.

Chromosome Configurations.—Three plants of *flavens.ᶥDevil's Gate* had ☉ 4, ☉ 4, 3 pairs; 3 plants of *albicans.ʰDevil's Gate* had ☉ 12, 1 pair.

Pollen Counts.—(flava, 1 pl.) good 228, inactive 11, empty 304. Total 543. (albata, 1 pl.) good 217, inactive 193, empty 987. Total 1397.

1931:22 *Oe. (grandiflora × franciscana deV.)* (1930:16, pl. 2 × 1930:14, pl. 2).

Seed germination 75 per cent (80 seed); 8 plants grown to maturity (5 *truncatae*, 3 *acutae*).

acuens.ʰfranciscana deV. Acuens contributed largely to the general habit, the plants being tall (1 m. or over), with well developed central shoots. *Acuens* influence was also seen in the light green foliage, white midribs, green leaf margins, erect position of bracts in young floral tips, and in the slender buds with long delicate tips: *ʰfranciscana* was responsible for stem coloration, both below and at the tips, red papillae, the rather wavy character of the foliage, reddening of the bracts, bud cone color and dense pubescence on the buds. The 2 complexes agreed in producing rather broad leaves with appressed marginal hairs, long styles, large flowers and long fruits.

truncans.ʰfranciscana deV.—Plants were typical *truncatae* in habit, with central shoots (110 cm. high), and relatively short, erect rosette branches. Further examples of *truncans* influence were seen in the narrower, more wavy leaves, with reddish midribs and brown flecks when young; spreading and smallish bracts, giving to the young floral tips a flat, compact structure; and slightly stouter, thicker-walled buds. *ᶥfranciscana* gave to the stem tips a red color, and produced red papillae, occasional traces of red on the bracts, and red pigmentation on the bud cones (usually seen only toward the end of the flowering period). Complexes were jointly responsible for the bright red basal stem color, appressed marginal hairs, long styles and large flowers. Buds were intermediate in pubescence, the hairs being less numerous and shorter than in *franciscana*.

Chromosome Configurations.—Two plants of *acuens.ʰfranciscana*

had ☽ 4, ☾ 4, 3 pairs; three plants of *truncans.ʰfranciscana* had
☉ 14.

Pollen Counts.—(acuta, 1 pl.) good 333, inactive 5, empty 69.
Total 407. (truncata, 1 pl.) good 325, inactive 17, empty 471.
Total 813.

1931:23 *Oe. (grandiflora ✕ "Johansen")* (1930:16, pl. 2 ✕ 1930:
10, pl. 3).

Seed germination 75 per cent (80 seed); 30 plants transferred
to field (16 *acutae*, 11 *truncatae*, 1 dwarf aberrant of undetermined
composition).

acuens.ʰJohansen.—Plants 110 cm. high, with strong central
shoots, having the habit typical of *acutae* in general. *Acuens* sup-
pressed the marginal leaf color found in *Johansen*, appressed the
marginal hairs, and caused bracts to stand erect in young floral tips,
giving the loose tips characteristic of *acutae*. *ʰJohansen* expressed
itself by the presence of a fairly strong red pigmentation on the
lower half of the stems, red stem tips and red papillae; in the slight
crinkling and waviness of the leaves, and weak red pigmentation
on the under side of the bracts and on bud cones. The complexes
were in agreement in producing a light green foliage, rather broad
leaves, long slender buds with long delicate sepal tips, long styles
and fruits, and large flowers.

One plant was variegated throughout, and 2 others were varie-
gated in restricted regions. Of the latter, one showed yellow over
green, the other green over yellow (see reciprocal, below).

truncans.ʰJohansen.—Plants ca. 130 cm. high, with strong cen-
tral shoots, and shorter rosette branches than those of *acutae*. The
presence of *truncans* was seen in the increased intensity of basal
stem coloration, reduction in number of long stem hairs and con-
sequently of red papillae; narrower, slightly darker, somewhat wa-
vier leaves than in *acutae*; slight traces of red color in midribs; green
leaf margins and appressed marginal hairs; smallish, brown-tipped
and spreading bracts, forming flat-topped, compact floral tips; some-
what thickened sepals and denser, somewhat appressed pubescence
on cones. *ʰJohansen* gave to the plants their purple stem tips, red
papillae, slightly reddened bracts and bud cones; and cooperated
with *truncans* in producing long buds with long sepal tips, long
styles and fruits, and large flowers.

Chromosome Configurations.—Three plants of *acuens.ʰJohansen*
had ☉ 4, 5 pairs; 3 plants of *truncans.ʰJohansen* had ☉ 14.

Pollen Counts.—(acuta, 1 pl.) good 284, inactive 21, empty 37.
Total 342. (truncata, 1 pl.) good 235, inactive 6, empty 773.
Total 1014.

1931:54 *Oe.* ("*Johansen*" $\times$ *grandiflora*) (1930:10, pl. 1 $\times$ 1930: 16, pl. 2).

Seed germination 86 per cent (80 seed). Most of the plants were yellowish, only 4 green plants appearing from 50 germinating seeds. The chlorotic plants were *acutae;* all died before they were 2 months old. The green plants were *truncatae;* they grew to be 120 cm. high, and resembled exactly their reciprocals (see next pedigree above).

Chromosome Configuration.—Two *truncatae* showed, like their reciprocals, $\odot$ 14.

1932:72 *Oe.* ("*Hall 30*" $\times$ *r-lamarckiana*) (1931:66, pl. 1 $\times$ 1931: 36, pl. 2).

Seed germination 62 per cent (100 seed); 30 plants transferred to field, all *velutinae.*

Plants were ca. 125 cm. high, with tall, erect branches, some with central shoots. On the whole, they approached the female parent in habit and general appearance, but had somewhat shorter internodes, slightly stouter buds, and appressed marginal hairs. Apart from factors modifying general habit, the complexes contributed by the 2 parents are quite similar in their phenotypic effects.

Chromosome Configuration.—The *Hall 30* parent in this cross had $\odot$ 4, 5 pairs, and produced therefore 2 genoms, α *Hall 30* and β *Hall 30*. Data from other crosses indicate that α *Hall 30* should give $\odot$ 4, 5 pairs with *velans,* and β *Hall 30* should give $\odot$ 6 with *velans.* Five F_1 plants were examined cytologically; 4 of them had $\odot$ 4, 5 pairs, and one had $\odot$ 6, 4 pairs, as expected.

1932:74 *Oe.* ("*Hall 30*" $\times$ *grandiflora*) (1931:66, pl. 1 $\times$ 1931:60, pl. 1).

Seed germination 84 per cent (100 seed); 30 plants transferred to field.

In early stages, no distinctions were observed between *acutae* and *truncatae*. When the plants were about ready for transplanting to the field, some began to show signs of chlorosis. This became pronounced as soon as the plants were set out, and they succumbed before the end of the season. Some survived long enough, however, to make it clear that they were *acutae.*

truncatae.—Plants had the strong central shoots characteristic of *truncans* combinations (150 cm. high), and erect rosette branches. Owing to the presence of *truncans,* the stems were a deep red below, red papillae and long hairs were few, bracts were brown-tipped and strongly flaring above, and bud pubescence was dense and somewhat appressed. The influence of *Hall 30* was seen in the presence of reddened stem tips, red papillae, relatively long internodes, traces

of red on bracts and bud cones, and traces of bowing of the sepal tips.

Chromosome Configuration.—Two plants had each ☉ 14. Which of the genoms of *Hall 30* (α or β) was represented is unknown.

1932:71 *Oe.* ("*Hall 30*" × *suaveolens*) (1931:66, pl. 1 × 1931:59, pl. 7)

Seed germination 34 per cent (100 seed).

Since *acuens* and *flavens* are so similar, it is not surprising to find that *Hall 30* plastids react similarly with both complexes. Plants were pale until set in the field; they rapidly became more chlorotic under the full sun, and died, none surviving beyond the end of July.

1932:64 *Oe.* ("*Heusi*" × *grandiflora*) (1931:69, pl. 8 (☉ 4) × 1931: 60, pl. 1).

Seed germination 68 per cent (100 seed); 30 plants transferred to field. Distinctions between *acutae* and *truncatae* became noticeable soon after transfer to the field, because of the fact that the *acutae* became somewhat chlorotic under the full sun (17 *acutae*, 13 *truncatae*).

acutae.—These plants had a hard struggle, due to chlorosis; all but 4 succumbed before flowering. Thus, *Heusi* plastids, like those from most California strains, are sensitive to the *acuens* gene complex, but on the whole they are somewhat more resistant than those of some other races.

Plants uniform, 80 cm. high, with central shoots. The *Heusi* genoms contributed red papillae, purple stem tips, and slight traces of red pigmentation on bud cones. *Acuens* influence was seen most clearly in habit, and in the character of the floral tips. The parental complexes were alike in producing little stem coloration, broad, rather flat leaves with white midribs and appressed marginal hairs, slender buds with long sepal tips, large flowers and long fruits.

truncatae.—Plants 115 cm. high, with central shoots, dark green. *Truncans* imparted bushy habit, deep pigmentation of the base of the stems, reduction in number of long hairs and red papillae on the stems, narrow, somewhat wavy dark green leaves, traces of red in the midribs, flaring bracts, truncate floral tips, and dense appressed pubescence on the bud cones. Red papillae, reddened stem tips, reddened marginal teeth, and slight traces of red on bud cones were inherited from *Heusi*. Certain characters were produced jointly by *truncans* and the *Heusi* genoms, namely: appressed marginal hairs, slender buds with delicate sepal tips, long styles and fruits, large flowers.

Chromosome Configurations.—Two *acutae* were examined, one of

which had 7 pairs (β *Heusi.acuens*), the other ⊙ 4, 5 pairs (α *Heusi.
acuens*). Two *truncatae* had ⊙ 14. There is no way of knowing
whether these two had the α or the β *Heusi* genom.

1932:65 *Oe.* ("*Heusi*" ✕ *r-lamarckiana*) (1931:69, pl. 8 (⊙ 4) ✕
        1931:36, pl. 2).

Seed germination 6 per cent (100 seed); it is probable that seed
was collected too young. Five plants transferred to field. All were
velutinae.

Plants like *Heusi* in habit, but smaller and stockier. Foliage was
more crinkly-wavy than in *Heusi*, and the buds were stouter, with
shorter, blunter sepal tips. Fruits were stouter. Most of the re-
maining characters of the hybrids were derived from both parents,
including slightly reddened stems, purple stem tips, broad leaves,
white midribs, green margins, appressed marginal hairs, large flow-
ers, pigmented bud cones, long styles.

Chromosome Configurations.—Two plants were examined. One
had ⊙ 6 (α *Heusi.velans*); the other had ⊙ 4, ⊙ 6 (β *Heusi.velans*).
These were the configurations expected in view of the fact that
α *Heusi* is like [h]*Dalton*, and β *Heusi* like *acuens*, in respect to seg-
mental arrangement.

1931:55 *Oe.* ("*Johansen*" ✕ *r-lamarckiana*) (1930:10, pl. 6 ✕ 1930:
        2, pl. 13).

Seed germination 95 per cent (80 seed): 15 plants transferred
to field; all plants were *velutinae*.

Plants 90 cm. high, stockier than *Johansen*, robust, mostly with
central shoots, probably due to the influence of *velans*. Apart from
habit characters, [h]*Johansen* and *velans* differ chiefly in genes affect-
ing foliage color, marginal hairs and bud stoutness. The plants
were darker than *Johansen*, with appressed marginal hairs, and buds
somewhat stouter than in *Johansen*. From both parents were de-
rived weak basal stem color, purple stem tips, red papillae, broad,
rather wavy leaves, white midribs, red bracts and buds, large flow-
ers, long styles.

Chromosome Configuration.—Two plants were examined and both
showed the expected configuration, namely, ⊙ 6, 4 pairs.

1931:33 *Oe.* (*r-lamarckiana* ✕ "*Johansen*") (1930:2, pl. 1 ✕ 1930:
        10, pl. ?).

Seed germination 96 per cent (80 seed); 30 plants transferred
to field (17 *velutinae*, 13 *laetae*).

Velutinae were often chlorotic. Of the 17 set out in the field,
3 died, one recovered a dark green color, and altogether 7 plants
bloomed. These were identical in all respects with their reciprocals

(see above), except that on the whole they were somewhat smaller and less vigorous.

lactae.— Plants 90 cm. high, without central shoots. They were typical *lactae* in appearance. *ʰJohansen* succeeded in producing the following effects in opposition to *gaudens:* red stem tips, red papillae, a slight red cone coloration, and lengthened fruits.

Chromosome Configurations.—Two plants of *velans.ʰJohansen* were examined. Both were like their reciprocals in showing ☉ 6, 4 pairs. Three plants of *gaudens.ʰJohansen* showed ☉ 10, 2 pairs. This was expected since *ʰJohansen* has the same segmental arrangement as *ʰDalton,* which gives ☉ 10 with *gaudens.*

Pollen Counts.—(velutina, 1 pl.) good 310, inactive 0, empty 92. Total 402. (laeta, 1 pl.) good 253, inactive 5, empty 142. Total 400.

1932:46 *Oe.* ("*Johansen*" × *muricata*) (1930:10, pl. 6 × 1930:1, pl. 9).

Seed germination 86 per cent (49 seed). Seedlings were entirely lacking in chlorophyll, and died when a few days old. *Johansen* plastids are therefore unable to function in the presence of the combined *ʰJohansen* and *curvans* complexes.

1933:24 *Oe.* ("*Mateo*" × *shulliana*) (1931:4, pl. 4 × 1931:72, pl. 7).

Seed germination 67 per cent (100 seed); 30 plants transferred to field.

All plants were *ʰMateo.maculans.* Some of the plants were a good green and exactly resembled their reciprocals. Most were more or less chlorotic, however, and some failed to survive the summer. Except for the difficulty experienced by *Mateo* plastids in the presence of the *maculans* gene complex, no differences were noted between reciprocals (see next pedigree).

Those plants which bloomed showed segregation with respect to habit, in the manner typical of *Mateo* hybrids. There were 7 dwarfs and 8 of the elongate type.

Chromosome Configuration.—Two plants were found to have ☉ 8, 3 pairs.

1933:16 *Oe.* (*shulliana* × "*Mateo*") (1931:72, pl. 7 × 1931:4, pl. 10).

Seed germination 92 per cent (100 seed); 30 plants transferred to field. There were 6 *maculatae*, the rest *jugatae.* In both classes, segregation was found in respect to habit.

maculatae.—Plants 90 cm. tall (elongate type), 55 cm. (dwarf type); 3 plants were elongate, 3 were dwarf; the differences between

these types have been mentioned previously. *Maculans* contributed the following visible traits: brilliant purple basal stem coloration, absence of fine downy pubescence on stems, light green foliage, red midribs, brown flecks on young leaves; short buds, short delicate, somewhat spreading sepal tips; absence of glandular pubescence on cone, shortened style, small flowers. *Mateo* contributed stem tip color, reddened leaf margins, slight reddening of under surface of bracts, fairly strong cone color, dense hirsute pubescence on buds. Both complexes produce red papillae, but the hybrids had the delicate papillae of *maculans*, rather than the coarse papillae of *Mateo*. Appressed marginal hairs are characteristic of both complexes.

jugatae.—Plants 90 cm. tall (elongate type), 60 cm. (dwarf type); 9 plants were elongate, 15 were dwarf. *Jugens* appressed the basal stem coloration of *Mateo*, reduced the number of red papillae, but allowed them to grow large; thickened foliage, and imparted to it a greyish caste; almost suppressed cone color; shortened and thickened the buds; reduced the size of flowers, especially the petals; reduced style length somewhat, caused bud pubescence to lie forward. *Mateo* produced strongly purpled stem tips, red papillae, purple leaf margins, and slight reddening of bracts and bud cones. Both long and short hairs were present on the buds.

Chromosome Configurations.—The *Mateo* plant used in this cross was a different one from that used in the reciprocal. It had ⊙ 4, 5 pairs, instead of the 7 pairs possessed by the other plant. It was consequently capable of forming 2 types of genom, one of which was probably identical in segmental arrangement with that produced by the other plant, the other differing from it by one segmental interchange.

Maculatae.—Three plants were studied, and all had ⊙ 10, 2 pairs. This, it will be noted, is a different configuration from that found in the reciprocal (which had ⊙ 8). It differs from the latter, however, by only a single interchange, and the difference is probably due to the fact that these 3 plants represent the genom which is not identical with that possessed by the plant with 7 pairs.

Jugatae.—Two plants were studied cytologically. One of these had ⊙ 12, 1 pair, the other had ⊙ 10, 2 pairs. The difference between these (a difference of one interchange) is no doubt due to the presence of ⊙ 4 in the *Mateo* parent.

1931:10 *Oe. (muricata × "Dalton")* (1930:1, pl. 11 × 1930:11, pl. 2).

Seed germination 40 per cent (50 seed); 15 plants transferred to field. All plants but one were *rigens*.^h*Dalton*. The one exception was the metacline, *curvans*.^h*Dalton*.

rigens.'*Dalton.*—Plants 1 m. high, with central shoots, typical *rigidae*. In all cases where *rigens* and ʰ*Dalton* clearly differed in their effects upon the phenotype, *rigens* dominated.

*curvans.*ʰ*Dalton.*—The single plant was low, without central shoot, a typical *curvata*. The influence of ʰ*Dalton* upon the phenotype was difficult to recognize, in view of the strong dominance of *curvans* characters. One branch had leaves with yellow borders, showing the presence of *Dalton* plastids in certain regions.

Chromosome Configurations.—Two plants of *rigens.*ʰ*Dalton* had ⊙ 8, 3 pairs; the single plant of *curvans.*ʰ*Dalton* had ⊙ 8, ⊙ 4, 1 pair.

Pollen Counts.—(rigida, 1 pl.) good 207, inactive 270,[5] empty 595. Total 1072. (curvata, 1 pl.) good 229, inactive 6, empty 621. Total 856.

1931:9 *Oe.* (*muricata* × "*Devil's Gate*") (1930:1, pl. 9 × 1930:12, pl. 11).

Seed germination 48 per cent (50 seed); 15 plants transferred to field.

All plants were typical *rigidae*, 1 m. high, with central shoots. The culture was very similar to *rigens.*ʰ*Dalton*, being distinguished from it principally by slightly broader leaves, somewhat redder stem coloration, and occasional traces of red on bud cones, all of which were due to ʰ*Devil's Gate.*

Chromosome Configuration.—Four plants showed ⊙ 8, 3 pairs, the expected configuration in view of the configuration of *ringens.*ʰ*Dalton.*

Pollen Count (1 pl.).—Good 206, inactive [5] 299, empty 304. Total 809.

1931:8 *Oe.* (*muricata* × "*Johansen*") (1930:1, pl. 9 × 1930:10, pl. 3).

Seed germination 62 per cent (50 seed); 15 plants transferred to field. Two metaclines, *curvans.*ʰ*Johansen.*

*rigens.*ʰ*Johansen.*—Plants over 1 m. high, with central shoots. They resembled the last two cultures in most particulars, but differed in being a bit taller, in having slight traces of red in midribs, and on bracts and hypanthia, more red on the cones (although still weak), and longer buds. The leaves were broadish, as in *rigens.*ʰ*Devil's Gate*, the stems scarcely reddened, as in *rigens.*ʰ*Dalton.*

*curvans.*ʰ*Johansen.*—The plants were typical *curvatae.* The buds were longer than in *curvans.*ʰ*Dalton*, and somewhat reddened

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[5] Included in this category are unshrunken grains showing no signs of digestion of starch, even in the wings.

on hypanthia and cones, thus shewing some influence of *Johansen*. A number of branches showed chimaeral conditions with respect to plastids, indicating the presence of *Johansen* plastids in certain regions.

Chromosome Configurations.—Three plants of *rigens*.*Johansen* showed ⊙ 8, 3 pairs; one plant of *curvans*.*Johansen* had ⊙ 8, ⊙ 4, 1 pair. These were expected in view of configurations reported in the last two pedigrees.

Pollen Counts.—(rigida, 1 pl.) good 200, inactive 417, empty 342. Total 959. (curvata, 1 pl.) good 259, inactive 6, empty 425. Total 690.

1933:15 *Oe.* (*nobska* × "*Mateo*") (1931:73, pl. 13 × 1931:4, pl. 10).

Seed germination 97 per cent (100 seed); 30 plants transferred to field. All were *pubens*.*Mateo;* 16 had the dwarf habit, 14 the tall habit, thus showing the segregation characteristic of *Mateo* hybrids.

Plants with central shoots, dwarf type reaching 65 cm., tall type reaching 90 cm. In addition to the splitting in habit, *Mateo* influence was chiefly seen in the presence of red pigment at stem tips, red papillae, broad leaves, occasional traces of pigment in midribs, and weak pigmentation of hypanthia and cones. The influence of *pubens* was most noticeable in suppressing basal stem coloration, eliminating marginal color of leaves and bract coloration, in flattening the floral tips, and reducing bud and flower size. On the whole, the dwarf plants resembled *Mateo*, whereas the tall plants were rather typical of *pubens* combinations.

Chromosome Configuration.—The four plants which were examined had ⊙ 12, 1 pair.

1933:19 *Oe.* (*oakesiana* × "*Mateo*") (1931:71, pl. 3 × 1931:4, pl. 10).

Seed germination 76 per cent (100 seed); 15 plants transferred to field. Plants showed segregation into tall and dwarf types (7 talls and 8 dwarfs).

Plants bushy, with central shoots, the tall plants up to 100 cm., the dwarfs up to 70 cm. *Mateo* showed itself in the presence of red papillae, slight traces of red at stem tips, flattish foliage, reddish coloration on under side of bracts, and long style. *Accelerans* reduced the amount of pigmentation on the stem, bracts and bud cones, prevented pigmentation of midribs, reduced the size of buds and petals, and narrowed the fruits. The plants were peculiar in having buds which were much too small to accommodate the fully developed style and stigma, hence the stigma was pushed out from

the bud a day or two before anthesis, and spread its lobes about
1 cm. beyond the sepal tips.   The petals were narrow, and occa-
sionally defective, and the stamens, which were long, opened only
rarely, being almost wholly sterile.

   Chromosome Configuration.—Four plants were examined cyto-
logically, all of which had ⊙ 12, 1 pair.

   Pollen Count (1 pl.).—Good 24, shrunken with contents 2, empty
130.   Total 156.

1933:20 *Oe. (oakesiana* × "*Mono*") (1931:71, pl. 3 × 1931:5, pl.
      10 [8 pairs]).

   Seed germination 72 per cent (100 seed); 30 plants set out in
field.

   Plants bushy, with central shoots.   The heterozygous character
of the *Mono* parent was evident in the lack of uniformity in F_1 with
regard to certain characters, namely, cone color (13 pink, 17 green
or slightly pinkish); stem tip color (17 red, 13 green); height (16
tall, average 90 cm.; 14 short, average 55 cm.), and habit (central
shoot much exceeding rosette branches in 15, equal to branches in
10, shorter than branches in 5).   Cone color and stem tip color were
peculiar in showing a perfect negative correlation, a situation not
found in the *Mono* parent, where both types of coloration are pres-
ent.   Characters attributable to the *ʰMono* genom were: reddened
marginal glands in leaves, slight basal reddening on stems, red
papillae, slight reddening of bracts and cones in some plants, heavy
glandular pubescence on buds, long styles.   Those attributable to
accelerans were white midribs, dark green foliage, relative lack of
long hairs on stems and buds, wavy bracts, greatly flattened floral
tips, small buds, short petals, slender fruits.   In addition to cone
color of the usual type, all but one plant showed a peculiar red spot
at the top of the cone, between each two sepal tips.   This promi-
nent feature of the hybrid is not present in either parent, and may
be due to the interaction of genes from both parents.   Styles were
long, breaking through the sepals 2 or 3 days before blooming, the
stigma lobes being exposed precociously.   Anthers were mostly
sterile.

   Chromosome Configuration.—Two plants showed ⊙ 12, 2 pairs,
one pair being diminutive in size.   The presence of the ⊙ 12 was
expected in view of its presence in *oakesiana* × *Mateo*.   The pres-
ence of the extra pair of diminutive chromosomes was in keeping
with its presence in other crosses involving the *Mono* parent with
8 pairs.

   Pollen Count (2 pls.).—Good 339, shrunken with contents 21,
empty 2300.   Total 2660.

1933:18 *Oe.* (*ostreae* × "*Johansen*") (1931:70, pl. 4 × 1931:2, pl. 9).

Seed germination 85 per cent (100 seed): 15 plants transferred to field.

Plants ca. 1 m. tall, mostly without central shoots, but with sub-erect rosette branches. The presence of *fascians* was seen in stem characters, including the light pink basal coloration and distribution of apical pigment, as well as the dense hoary pubescence. Other *fascians* characters were narrow leaves, appressed marginal hairs, strongly flaring bracts, strong pink coloration of pulvini and of bases of hypanthia, appressed pubescence on buds, pink-tipped sepal teeth, small petals. [h]*Johansen* was chiefly in evidence in the bright red pigmentation of the under side of the bracts, excessively slender buds, with long delicate sepal teeth, long styles. Both complexes had a part in the production of red papillae, light green foliage, bright red cone color. Two outstanding characteristics of *fascians* were not observed, namely, fasciated tips and deformed or absent petals. A third characteristic, the intense red coloration of the leaves when old, was not striking.

Chromosome Configuration.—Three plants showed ⊙ 8, 3 pairs.
Pollen Count.—Good 400, inactive 359, empty 349. Total 1108.

1931:13 *Oe.* (*suaveolens* × "*Johansen*") (1930:15, pl. 15 × 1930:10, pl. 6).

Seed germination 68 per cent (80 seed): 30 plants transferred to field (11 *albatae*, 19 *flavae*).

flavens.[h]*Johansen.*—Plants 1 m. high, with central shoots. [h]*Johansen* contributed moderate red pigmentation on the lower stems, red papillae, red stem tips, reddened bracts, long buds with long slender sepal tips, abundant pubescence on buds, traces of pigmentation on cones, and long slender fruits. *Flavens* flattened the leaves, shortened the styles, and reduced flower size. Certain features, such as light green foliage color, broad leaves, white midribs, upright bracts, and slender buds, were more or less characteristic of both complexes. In general appearance and habit, the plants were rather typical *flavae*.

albicans.[h]*Johansen.*—Plants 90 cm. high, and, like most *albatae*, unable to develop central shoots. Leaves narrower, longer and darker green than in *flavae*, buds hairier, stouter, thicker-walled, fruits stouter. [h]*Johansen* was able to impart a slight reddish tinge to the stems, a larger quantity of pigment to the stem tips than *flavae*, red papillae (few in number), reddened bracts and cones. Style was long, flowers moderate in size.

Chromosome Configurations.—Three *flavae* showed ⊙ 4, ⊙ 4, 3 pairs; 3 *albatae* had ⊙ 12, 1 pair.

Pollen Counts.—(flava, 1 pl.) good 256, inactive 2, empty 105. Total 363. (albata, 1 pl.) good 237, inactive 332, empty 1003. Total 1572.

The reciprocal of this cross resulted in pale green seedlings which soon died.

D. *Discussion of the Behavior of Certain Characters Found in California Races*

Lack of facilities for more extensive study has made it impossible to grow F_2s, and hence to follow the characters displayed by the California races beyond the first hybrid generation. Nevertheless, it has been possible to learn something with regard to the genetical basis of phenotypic characters in these forms, as follows:

1. California races so far studied have differed from one another in many particulars, including habit, degree of stem coloration, presence of red papillae, breadth, color and flatness of leaves, marginal color, position of marginal hairs, midrib color, bract and bud-cone color, stoutness of buds, length and position of sepal tips, fruit size. On the other hand, they have shown a fair degree of similarity with respect to certain other features, such as the presence of relatively few buds in a single flowering tip, large flowers, terminally-inserted sepal tips, long styles, good pollen.

2. The behavior of certain of these characters, as far as this has been analyzed through studies of F_1 hybrids, will now be discussed:

(*a*) *Presence or Absence of Central Shoots.*—It is probable that many plants which failed to develop central shoots in my garden would not have had much difficulty if the soil had been richer. The consistent difference between complexes, however, in this respect, when grown in my garden, shows clearly that hereditary differences exist, making it more difficult for some combinations to develop central shoots than for others. Those which have strong central shoots have evanescent rosettes, as opposed to those with no central shoots.

Most of the California races so far analyzed have shown a weak tendency toward central shoot production. Central

shoots have never been observed in *Hall 34* and *Heusi*.
They have been formed only occasionally in most of the others.
Only *Mono* and the dwarf form of *Mateo* have shown any
strong tendency toward their development, and even in
these, individuals without central shoots have been by no
means uncommon.   California races which have long been
known, namely, *hookeri deV.* and *franciscana*, share the com-
mon difficulty of central shoot production.

In crosses between California races, we find no greater
tendency toward the production of central shoots than in the
races themselves, in spite of their greater vigor.   In crosses
with other races, the failure to produce central shoots is on
the whole recessive to their production.   Consequently,
crosses with certain non-California complexes which have a
strong tendency toward central shoot production, such as
excellens, punctulans, rigens, acuens, truncans, flavens, pubens,
maculans, jugens, accelerans, yield F_1s having central shoots
and a bushy habit.   On the other hand, crosses with certain
other complexes, like *velans, gaudens, albicans, curtans,*
elongans and *curvans*, result in hybrids in which central shoots
are frequently or generally absent.

(*b*) *Basal Stem Coloration and Midrib Color.*—In no cases
so far observed have California races shown the presence of *R*.
In many cases, however, they have shown some tendency
toward reddening on the upper surface of the midribs.   This
tendency has been found especially prominent in *Mono*, but
has also been strong in *Mateo*, and in certain plants of *Devil's*
Gate.   Certain races have failed to show any trace of this
coloration, namely, *Hall 34, Heusi, Johansen* and *Dalton;* and
others have shown it but weakly.

Correlated closely with this character is basal stem colora-
tion.   On the whole, it seems clear that the stronger the basal
stem coloration, the more likely is red pigmentation to occur
on the midribs.   In other words, the midrib coloration char-
acteristic of California strains, including *hookeri* and *francis-*
cana, is a product of the gene or genes producing basal stem
coloration.

In outcrosses with complexes which do not carry factors for this type of pigmentation, it appears to act more or less in dominant fashion, stem color being intensified, and midrib color appearing, in many such hybrids. Thus, traces of red coloration are found in the midribs in such hybrid combinations as *ʰDevil's Gate.acuens*, *ʰDevil's Gate.r-velans*, *ʰDevil's Gate.r-gaudens, pubens.ʰMateo*.

At best, this type of midrib coloration is unsatisfactory for genetical study, since it is usually weak, and is variable in its appearance, often showing in only a few leaves, under conditions of intense illumination. As suggested by Emerson (1929), multiple factors are probably involved.

(c) *Marginal Leaf Coloration.*—This is a different character from that described by Renner and ascribed by him to a dominant gene, *M*. This is shown by the fact that *M* is absent in *hookeri* (Renner 1925, p. 135), which nevertheless has the marginal coloration under discussion. All of the California races so far studied except *Devil's Gate* have shown this character, which consists in a reddening or purpling of the margins, especially in young rosette leaves, but often in mature leaves also.

In all hybrids so far studied between California races, marginal coloration has been present, except in those which have had *Devil's Gate* as one of the parents. Whether the latter has been used as male or female parent has made no difference—its hybrids have been consistent in failing to show the coloration. This seems to suggest that the coloration is recessive to green margins. However, hybrids between California races and races from other regions have not always supported this suggestion. Thus, while the 10 hybrid combinations involving *Dalton*, and the 1 combination involving *franciscana*, above described have all had green margins, and thus have resembled their extra-California parents, the 2 *hookeri* hybrids, as well as 2 hybrids of *Hall 30* and one of *Mono* have had purple margins, like their California parents; and *Mateo, Heusi* and *Johansen* have formed about as many hybrids with purple margins as without (in *Mateo*, 2 with, 2

without; in *Heusi*, 1 with, 1 without; in *Johansen*, 4 with, 7 without). In some cases, therefore, colored margins seemed to act as a dominant. It is possible that inhibiting factors are present in some complexes and absent in others; or it may be that multiple factors are responsible for the greater expression of the character in some cases than in others.

(*d*) *Marginal Hair Position.*—*Johansen, Dalton* and *hookeri* have shown, in all plants studied, erect marginal hairs (*i.e.*, hairs in the plane of the leaf surface, but perpendicular to the edge of the leaf); *Mateo, Mono, Heusi* and *franciscana* have shown appressed marginal hairs. The other California races have shown segregation with respect to this character in the first, and in some cases, in subsequent generations (including *Devil's Gate, Hall 21, Hall 30, Hall 34*). Erect marginal hairs behave in crosses as a simple Mendelian recessive, for which the symbol *e* is suggested. This character has not been observed in any race from outside California.

(*e*) *Bract and Bud-cone Color.*—It is worthy of note that bud-cone coloration and the presence of red pigmentation on the under side of the bracts are apparently completely correlated—at least as far as the California races are concerned. The stronger the color of the sepals, the stronger the bract coloration, on the whole; when bud-cones are weakly colored, the bracts are also weakly colored, often showing no color until near the end of the season. The varying degrees in which this form of pigmentation appears in different forms suggests the presence of multiple factors, as postulated by Emerson (1929). Cones and bracts were more or less reddened in *Johansen, Devil's Gate* (very slightly), *Mateo, Mono* (segregation), *Hall 21* (segregation), *Hall 30* (segregation), *Hall 34, Heusi, hookeri,* and *franciscana.* They were entirely green in *Dalton.*

(*f*) *Stem Tip Color.*—All California races have shown reddening of the stem tips except that certain plants of *Hall 21, Hall 34* and *Devil's Gate* have had wholly green tips. The amount of pigmentation has varied greatly in different races, and between different plants of a single race. However, no clear

correlation has been noted between stem tip coloration and any other character in the plant.

In outcrosses, this character has been able to express itself, to some degree, at least, whenever inherited from one parent, except in the case of *curvans* hybrids. *Curvans*.ʰ*Dalton* and *curvans*.ʰ*Johansen* both had wholly green tips, even though the California complexes in these cases carried a factor or factors for purpling. In some other instances, the amount of pigmentation was cut down in the hybrids to a mere trace. It is probable, as Emerson suggests (1929) that more than one pigmentation factor is involved in the production of this character.

Other characters displayed by the California races are already so well known that detailed comment regarding them is unnecessary. The characters have been listed above (p. 405) in respect to which these races have shown variation, as well as those in which they have shown constancy.

DISCUSSION

A. Extent of Phenotypic Differences Displayed by California Races under Garden Conditions, and its Significance

1. One of the chief problems confronting the student of species concerns the importance which should be ascribed to the factor of environment in species-making. When one is confronted by the existence in contiguous, but ecologically dissimilar regions, of what seem to be distinct geographical races, the problem is to determine to what extent the differences between such races are due simply to differences in the habitat, modifying the growth form, suppressing the action of certain genes, encouraging the activity of others; and to what extent they are due to actual genetical differences. To the extent to which their differences are due to environment, so that extent such divergent races should tend to lose their differences when brought under uniform climatic and edaphic conditions, as in an experimental garden. To the degree, however, to which their differences are due to actual genetical differences, to that degree should they tend to retain their differences, even under uniform conditions.

The strains described above would be considered by many taxonomists as geographical races of *hookeri*. They were collected in widely varying habitats, ranging from sandy sea-shores to semi-desert or alpine conditions, from sea-level to 9000 feet in elevation; and they were apparently very different from one another in many respects in the field. In the garden, they were, with the exception of the nearly identical *Hall 30* and *Hall 21*, quite distinct, when first grown, and have retained their distinctive characters from generation to generation. There can be no doubt, therefore, that many of the differences between California races are genetic in nature, and that the assemblage known as *hookeri* includes a variety of distinct biotypes, exhibiting anything but uniformity of genetical composition throughout its range.

This does not mean, however, that there may not be much variation in Nature which is due to the direct effect of environment. and which is superimposed upon such variations as are genetically induced. It should be of interest, therefore, not only to compare race with race under constant garden conditions, but to obtain a comparison of the behavior and degree of variation of each race, when grown in the garden, with its behavior in its natural habitat. It is hoped that such comparisons will become possible as the field studies now being carried on by Dr. Munz are completed, and that some indication will be forthcoming as to whether the external environment is of any importance in the direct modification of structural features, and the formation of taxonomically distinct entities.

2. In addition to finding constant racial differences between strains, variation of quite another sort has been found to be very common within California races, namely, segregation with respect to a number of characters, for which these races are evidently heterozygous. This segregation, together with the fact that different segmental arrangements are to be found in their genoms (vide infra). suggests that hybridization between distinct types has played a considerable role in the process which has produced the California Onagras as they

are today. This is quite in line with expectations, since the California forms are all large-flowered, open-pollinated forms, and cross easily with each other.

The phenotypic differences, therefore, seen under uniform garden conditions, are of two types: there are the constant racial differences, which indicate that distinct biotypes exist within the California assemblage; and in addition, there are the frequent differences in individual characters within races, due to heterozygosity, which suggest that inter-racial crossing has been a prominent factor in the phylogenetic history of the group.

B. Cyto-genetic Behavior of California Races

One of the most striking results of the present study has been the discovery that the California group as a whole behaves from the cyto-genetic standpoint quite differently in many respects from races from other regions. Up to the present time, *hookeri* and *franciscana* have constituted almost the only exceptions to the rule that wild races of *Onagra* are "complex-heterozygotes," *i.e.*, highly heterozygous forms, with their genes associated for the most part within a single linkage group, breeding true by reason of balanced lethals in this group, and showing in consequence of the presence of these lethals a high degree of gametic or zygotic sterility. Now it becomes apparent that *hookeri* and *franciscana* were but the first known exemplars of a type of genetic behavior which apparently characterizes the California area as a whole.

The California races differ as a unit from races from other regions in the following chief particulars, as evidenced by the data presented in the descriptive portion of this paper:

1. They give no evidence of the presence of lethal factors, either balanced or unbalanced. They all show high pollen fertility, as well as high seed germination (table 1), and the number of abortive ovules in their capsules is extremely low or entirely absent. In showing this combination of high pollen fertility and high seed germination, the California races differ greatly from races obtained from other regions. Furthermore, they give identical progenies when used recipro-

cally in crosses with other races. There are thus present none of the external phenomena which usually accompany and are caused by the presence of lethals, whether pollen or zygotic.

2. Three of the 11 strains have shown no indication whatever of the presence of heterozygous genes (*hookeri, franciscana, Johansen*), and in this respect are in strong contrast with the complex-heterozygotes of other areas.[6] The other strains have shown some indication of heterozygosity, slight in some cases, considerable in others. On the whole, however, they are probably much less heterozygous than the complex-heterozygotes from other regions.

3. Unlike complex-heterozygotes, the California forms have given no indication that their genes are for the most part associated into a single linkage group. On the contrary, independence of splitting has characterized those forms which possess heterozygous genes, thus indicating the presence of separate linkage groups. "Complexes" in the sense in which this term is used by Renner, therefore, are absent in the California forms, *i.e.*, these forms do not possess genoms which are passed on from generation to generation intact, in which independent assortment is completely or almost completely suppressed. In this, as in the foregoing respects, therefore, the California group is at present unique.

4. The California forms are also peculiar among the known *Onagras* in having a chromosome behavior in meiosis which shows comparatively little evidence of those unusual features which seem to characterize the sub-genus as a whole. As will be seen from table 1, paired chromosomes are the rule in California races. Of the 9 races recently brought under surveillance, 2 showed only paired chromosomes, and 6 showed entirely paired chromosomes in some (often a majority) of the plants. Moreover, in most of the individuals where circles were present, these were small. A total of 46 first generation plants belonging to these 9 races were studied

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[6] It is barely possible, of course, that *hookeri* and *franciscana* were in some slight degree heterozygous when first cultivated; but if so, such heterozygosity has since entirely disappeared.

cytologically, and these included 30 plants with all of their chromosomes paired (3 of these with extra chromosomal material), 10 plants with ⊙ 4, 5 pairs, and only 6 plants with more than 4 chromosomes involved in circles (2 ⊙s of 4 in 4 plants, ⊙ 6 in 1 plant, and ⊙ 8 in 1 plant).

It is evident that paired chromosomes, and therefore the presence of independent linkage groups, is characteristic of this assemblage. On the other hand, it is also clear that segmental interchanges have not been wholly lacking in the group, since some variation in segmental arrangement has been found. In other words, there is apparently nothing in the make-up of these plants that renders segmental interchange inherently incapable of occurring. This being the case, it will be interesting to bear in mind the question as to why there seems to be so little indication of interchange in these forms, in comparison with forms from elsewhere (vide infra).

Summing up the chief points with regard to the cyto-genetic behavior of California races, we find them to be in striking contrast to *Onagras* from other regions in the following respects:

(1) They show no evidence of lethals; (2) they are relatively (or entirely) homozygous; (3) they do not possess super-linkage groups; (4) and they have on the whole a chromosome behavior which is free from the peculiarities usually found in the sub-genus. Point for point, the California races, therefore, are characterized by an absence of those peculiarities, genetical and cytological, which have constituted the major problem of *Oenothera* cyto-genetics. This is no doubt a fact of primary phylogenetic importance. Why should *Onagras* from all other regions, so far as known, show a characteristic series of unusual genetical and cytological phenomena, while the group from California, practically alone among *Onagras*, is free of these peculiarities?

C. *Indications of Phylogenetic Relationship*

(a) *Relation of the California races to each other*

This matter will not be discussed in the present paper from the phenotypic point of view, inasmuch as judgment with regard to relationships based upon phenotypic resemblances must await a thorough taxonomic analysis of the California assemblage. Such a study is being carried out by Dr. Munz. I wish to point out, however, the bearing upon this problem of a study of the cytology of hybrids between these races, assuming, on the basis of arguments presented earlier (pp. 341–344), that the presence of a large number of paired chromosomes in a hybrid is indication that the genoms associating to form that hybrid are closely related genetically, as well as similar or identical in segmental arrangement.

A summarization of the cytological findings in hybrids between California races is presented in table 2. In all, the progenies of 33 such crosses have been studied cytologically, a number of them reciprocally, there having been represented in these progenies a total of at least 47 different combinations of the various segmental arrangements found in the parental races. A glance at the table shows that most of these had paired chromosomes. Of the 47 visibly different hybrid combinations, 43 combinations, or 123 of the 135 plants examined cytologically, had either nothing but paired chromosomes (20 combinations, including 56 plants), or at the most a circle of 4 (23 combinations, including 67 plants); 20 of the crosses involved genoms which were identical in segmental arrangement, 23 were between genoms which differed by only a single segmental interchange. Even the 12 plants which had more than 4 chromosomes involved in circles were composed of genoms which were not very different in their segmental arrangements. Eleven of them had 2 ⊙s of 4, or ⊙ 6 as their configuration, so that their genoms probably differed by but 2 interchanges. The single remaining plant had ⊙ 4, ⊙ 6, and may have been composed of genoms which differed by no more than 3 interchanges.

It is clear from this summary that the races from California have on the whole identical or nearly identical segmental arrangements (for the actual arrangements, see p. 426). On the basis of our previous argument (p. 341 ff.), the most reasonable assumption is that this is due to their all having had a relatively recent common origin—in other words, to their being phylogenetically close to each other.

A study of chromosome configurations in the hybrids between California races, therefore, suggests that these races are closely related to one another.

(b) Relation of the California races to races from other regions

In all, 53 crosses between California and non-California strains have been studied, involving 69 different combinations of segmental arrangements. Of these, 17 crosses (21 combinations) have been previously reported, and 36 (48 combinations) are presented for the first time in this paper. The chromosome configurations found in these 69 combinations have ranged all the way from 7 pairs at one end of the series to a circle of 14 at the other, and 12 of the 15 configurations which are possible in forms with 14 chromosomes have been found (see table 3).

Apparently, many of the complexes resident in areas removed from California show little evidence of close relationship to the complexes of the California type, judging from the fact that they give large circles with them. Nevertheless, some of these complexes have segmental arrangements which are essentially similar to those found in the California strains, and consequently give small circles or none with them. Thus, 4 combinations between California and non-California genoms have shown 7 pairs, indicating identical segmental arrangements; 10 combinations have had ⊙ 4, 5 pairs, the genoms probably differing therefore by but a single interchange; 7 combinations have shown ⊙ 6, 4 pairs, and 5 combinations have had 2 ⊙s 4, 3 pairs, or a total of 12 combinations whose components in all probability differ by no more than 2 interchanges. Thus, 26 of the 69 combinations which have been

studied cytologically were between genoms which probably differed by no more than 2 interchanges. In addition to these, 5 combinations had ⊙ 8; 2 combinations had ⊙ 4, ⊙ 6 and one combination had 3 ⊙s 4. The mathematical probabilities of the appearance of these configurations through the chance union of unrelated complexes are relatively slight, especially in the case of 3 ⊙s 4, and hence the chances are relatively great that the complexes forming these configurations were also rather closely related cytologically, actually differing by the minimum number of three interchanges necessary to produce these configurations. A considerable proportion of the combinations, therefore, have shown configurations which indicate a more or less close relationship in segmental arrangement between the associated genoms. Consequently, on the basis of the argument set forth above, the probability is strong that the complexes or genoms involved in these combinations are, from the genetical standpoint also, more or less closely related, *i.e.*, that they trace back to a relatively recent common ancestor.

The complexes from outside California which have thus shown evidence of a close relationship with the California type of genom are the following: *velans* (from *lamarckiana*), *flavens* (from *suaveolens*), *excellens* (from *chicaginensis*), *acuens* (from *grandiflora*), *rigens* (from *muricata*) and *fascians* (from *ostreae*). Two facts at once stand out as of particular significance from the phylogenetic standpoint:

1. Five of the 6 complexes in this list, in addition to *ʰhookeri* deV. and *ʰfranciscana*, have been analyzed genetically by Renner and his followers. It is significant that these complexes, which from the standpoint of segmental arrangement show a close affinity to the California group and to each other, have on the whole been found by Renner, quite independently and in advance of the findings of this paper, to be closely related genetically (see Fig. 19 in Hoeppener and Renner 1928, p. 23).

2. These complexes have been found in geographically widely separated regions. Three of them (*velans*, *flavens* and

rigens) belong to forms which were discovered in Europe, one was derived from Chicago (near Jackson Park), one from the banks of the Alabama River, near Mobile, Ala., and one from the vicinity of Falmouth, Mass. In spite of their close affinity, cytological and genetical, the regions in which they were discovered are widely scattered. Consequently, until the present we have had no reason to consider that the type of segmental arrangement possessed by this group belonged to any one geographical locality more than another. It now appears, however, that this type of arrangement is preeminently characteristic of the California area. In view of the unliklihood that complexes with similar segmental arrangements have had independent origins, and represent convergence in segmental arrangement (see p. 341 ff.), it seems logical, therefore, to assume that this particular type of segmental arrangement was originally native to the California area, and that it has become spread in one way or another to other parts of the *Onagra* range, so that it is now found in different areas (to an extent as yet undetermined), associated in all cases so far as known with complexes which are not of the far western type. We assume as a working hypothesis, therefore, that such species as *lamarckiana, suaveolens, grandiflora, chicaginensis, muricata* and *ostreae* are each made up of one complex which has been derived in comparatively recent times from the western area, and one complex which is not of the California type, whose derivation is as yet undetermined.

From the phylogenetic standpoint, this is a significant situation. It raises two questions: (1) How have California components succeeded in becoming a part of species in places distant from California? (2) Where have the components which are not of the California type come from? Is there any indication of relationship between them or clue to the region from which they have come?

With respect to the first question, it must be said not only that we know very little regarding the methods by which complexes of the California type have been spread to distant and scattered regions, but that we are not even certain how

many of the species containing these complexes are indigenous in the regions where they were found, and consequently we have almost no information regarding the geographical distribution of the complexes in question. Three of these complexes were found originally in Europe (*velans*, *rigens* and *flavens*), where *Onagras* are known not to be indigenous. The origin of two of these (*velans* and *flavens*) cannot even be guessed at present, since the species of which they are a part have never been found in North America, and may never have existed there (they may have resulted from the crossing of unrelated forms, brought into juxtaposition after their introduction into Europe). With regard to the third complex, *rigens*, the situation is perhaps clearer, for *muricata*, as found in Europe, is very similar to the muricatas of eastern North America; and since these are all small-flowered, self-pollinating types, the probability is that the muricatas of Europe are direct descendants in selfed lines from muricatas in this country—that they have not been derived by hybridization between unrelated American forms. It is reasonable to suppose, therefore, that *rigens* had essentially the same association before it came to Europe that it retains in Europe, and that its native habitat was in the eastern part of North America.

When we consider the 3 extra-California, but California-like, complexes which have been found in this country, we are confronted with the fact that they have been found near urban centers, and hence may have been brought into these regions along trade routes. *Excellens* belongs to *chicaginensis*, which was found by de Vries near Jackson Park, Chicago. Until a cyto-taxonomic survey reveals the range of *excellens* and *excellens*-like complexes, we must entertain with scepticism the assumption that Chicago actually lies within the range of complexes of this type. A similar situation is found in the case of *acuens*. *Grandiflora*, to which this complex belongs, was originally collected along the banks of the Alabama River, not far from Mobile. It has also been found in the suburbs of Mobile, where it was probably an escape

from gardens (see de Vries, 1914), and along the railroad near Castleberry, Ala. The possibility of artificial transportation to these localities must not be dismissed until evidence has been accumulated to show the natural range of this race. There is perhaps a greater chance that *fascians* (in *ostreae*) is native to the region near Falmouth, Mass., where it was found, in spite of the fact that this locality is close to the seacoast and to certain ports of entry; for *ostreae* is one of the *muricata*-like forms, and the muricatas are native in this general region.

Summing up our knowledge of the distribution of the extra-California, yet California-type complexes, the most we can say is that they were found in as widely separated localities as Europe, Chicago, Alabama and Massachusetts, and that there is a distinct possibility that some of them are indigenous in the regions where they were found. Whether this surmise is correct should be easy to determine, through the survey of *Onagra* now in progress.

As to the means by which these complexes have come to reside at such distant points from California we have at present no knowledge. Whether this distribution is to be ascribed to artificial transportation, or to natural migration remains to be discovered. Among the problems for future investigation, therefore, will be to ascertain the extent to which complexes of the California type are actually present in regions distant from California, and to trace the geographical spread and progressive modification of the California component in the wild *Onagra* populations of North America.

The second question has to do with the source of the complexes that are not of the California type. Is there any relationship between these, or any indication of the region in which they have originated?

With regard to relationships, we may say that, in addition to showing little affinity with complexes of the California type, they show on the whole little relationship to one another. There are some exceptions, *e.g.*, *rubens* (from *biennis*) and *gaudens* (from *lamarckiana*) are nearly identical, and *curvans*

(from *muricata*), *percurvans* (from *ammophila*), and *flectens* (from *cruciata*) are very similar (Hoeppener and Renner, 1928, p. 23). In addition to these there are at least 3 cases in which a complex is shared by distinct races, viz., *albicans* (found in *suaveolens* and *biennis*), *rubens* (found in *biennis* and *rubricaulis*), and *rigens* (found in *muricata* and *ammophila*).

Most of the non-California complexes, however, are un-related to any other known complex. Thus *tingens* of *rubricaulis, truncans* of *grandiflora, punctulans* of *chicaginensis, pingens* of *cruciata, curtans* and *elongans* of *cockerelli, deprimens* of *strigosa, jugens* of *shulliana*, and others, are, so far as known, quite unrelated to one another or to any known complex; and for that matter, the *rubens-gaudens* pair on the one hand, and the *curvans-percurvans-flectens* group on the other hand, are quite unrelated to each other or to any other known complex.

Where did all of these different complexes come from? That is a question which cannot be answered as yet. One can think of various ways in which they might have arisen—complexes may have been introduced from other centers of distribution, still to be ascertained; segmental interchanges and hybridization may have played their roles in transforming complexes, even of the California type, into entirely unrelated types. But until we know more of the geographical ranges of the different complexes or groups of complexes, we will be in no position even to guess at the truth in this regard. Another of the major objectives for further study will therefore be to analyze the *Onagra* population as far as possible with regard to the ranges of the non-California components, as an aid to ascertaining their origins and relationships.

(c) Conclusions

This is about as far as we can follow the story of Onagraceous phylogeny at the present time. The work is as yet too meager to give us a clear understanding of species relationships in general in *Onagra*, or to the way in which species have come to be where and what they are. As a result of the

findings herein presented, however, we have what seems to be a suggestion of certain of the outlines of the picture. On the one hand, we see in California a homogeneous group of closely related forms, alethal, with paired chromosomes and a characteristic type of segmental arrangement. On the other hand, we find in other regions a plexus of forms which are almost unknown as yet, but which, so far as known, have with few exceptions, balanced lethals and large circles of chromosomes. Some of the latter seem to bear no resemblance to the California group at all, but others are apparently combinations of a complex of the California type and a complex of an entirely different character.

The outlines of the picture, so far as we can make them out, seem to suggest that the California area is a center whence forms have spread into other regions. In those other regions they have either (a) crossed with races which have come from other centers or which represent earlier migrations from the same center; or else (b) they have become profoundly altered by interchange with respect to at least one of their genoms, one genom remaining in some cases more or less unmodified. Which of these alternatives will prove to be correct, or whether they are both partly correct remains to be determined on the basis of further work.

The work which has just been reviewed is but the beginning of a thorough survey of *Oenothera* taxonomy and phylogeny which is being carried out as a cooperative enterprise. The findings of this preliminary investigation make it possible to include among the objectives for future work the solution of the following specific questions: (1) To what extent has the California type of complex permeated into other regions, and to what extent has it become modified as it has spread? (2) What are the relationships of complexes which are not of the California type? Where and in what manner have they arisen? The answers to these and to other questions of a like nature will determine the way in which species in *Onagra* are to be defined, and will help us toward an understanding of the nature of species in general, and of the factors which are responsible for their origin, spread and survival.

D. *Segmental Arrangements of California Genoms*

The segmental arrangement of *hookeri* deV. has been taken as standard, and is written as follows (see Cleland and Blakeslee 1931):

$$1 \cdot 2 \quad 3 \cdot 4 \quad 5 \cdot 6 \quad 7 \cdot 8 \quad 9 \cdot 10 \quad 11 \cdot 12 \quad 13 \cdot 14$$

The arrangement of *excellens* is (Cleland and Blakeslee 1931):

$$1 \cdot 2 \quad 3 \cdot 4 \quad 5 \cdot 6 \quad 7 \cdot 10 \quad 9 \cdot 8 \quad 11 \cdot 12 \quad 13 \cdot 14$$

Dalton, Devil's Gate, Johansen.—These species have entirely paired chromosomes, and are therefore capable of producing but one type of gamete from the standpoint of segmental arrangement. Since *hDalton, hDevil's Gate* and *hJohansen* all give 7 pairs with *excellens* they have the same segmental arrangement as *excellens*. They should, therefore, give 7 pairs with each other, and ⊙ 4 with *hhookeri* and *hfranciscana* deV., which they do.

Mateo.—Plant no. 15 of the original culture, which became the progenitor of later generations, and also parent in most of the crosses involving *Mateo*, had 7 pairs, and therefore could produce but a single genom, *hMateo*. Since *hMateo* gives 7 pairs with *hDevil's Gate*, and ⊙ 4 with *hhookeri*, it also has the same segmental arrangement as *excellens*. In one cross (with *shulliana*), pl. no. 4 of the original culture was used. This plant also had 7 pairs. No attempt has been made, however, to determine whether or not this plant had the same segmental arrangement as plant no. 15. In 4 crosses (with *nobska* ♀, *oakesiana* ♀, *shulliana* ♀ and *Hall 21* ♀), plant no. 10 was used, which had ⊙ 4, and was therefore capable of producing gametes with 2 types of segmental arrangement. One of these gave with *jugens* (*shulliana* × *Mateo*) ⊙ 10, the other ⊙ 12. Since *sd 'franciscana* (which has the same segmental arrangement as *hMateo*) gives ⊙ 10 with *jugens* (Emerson and Sturtevant, 1931), it is evident that it is the former segmental arrangement which is comparable to the *hMateo* in plant no. 15. It may be designated as α *Mateo* (= *hMateo*), the other arrangement as β *Mateo*. α *Mateo* gives

7 pairs with *Hall 21*, as expected. Whether α or β *Mateo* functioned in producing $\odot$ 12 with *pubens* and $\odot$ 12 with *accelerans*, is unknown.

In all crosses where the configuration could be predicted on the basis of the assumption that [h]*Mateo* has a segmental arrangement identical with that of *excellens*, the predicted configurations were obtained.

Mono.—Two plants of the original culture had $\odot$ 4, and 2 plants had 7 pairs of normal chromosomes plus a diminutive pair, which behaved in normal fashion in meiosis. The 2 former plants should have yielded gametes with 2 segmental arrangements, the latter should have yielded but one type. Most of the *Mono* crosses involved a plant with 8 pairs, but a few utilized a plant with $\odot$ 4. The plant with 8 pairs had a segmental arrangement (so far as its normal chromosomes were concerned) identical with that of [h]*Mateo*, since it gave only pairs with it. This conclusion was borne out by the presence, in other crosses, of the configurations to be expected on such an assumption.

Hall 21.—Five of the 6 plants of the first generation had 7 pairs, and therefore but one type of segmental arrangement in their gametes (genom called [h]*Hall 21*). The one remaining plant had $\odot$ 4, but was not used in any kind of breeding work. [h]*Hall 21* gives 7 pairs with [h]*Dalton*, α *Mateo* and [h]*Mono*, and therefore has the same segmental arrangement that characterizes these genoms, as well as *excellens*.

Hall 30.—One plant of the first generation had 7 pairs, and 2 plants had $\odot$ 4. A single plant was used in all crosses and as parent of the next generation, and this individual had $\odot$ 4. Crossed with *hookeri* deV., this plant gave F_1 progeny with 2 configurations, 7 pairs and $\odot$ 4. Evidently, one genom had a segmental arrangement identical with that of [h]*hookeri*, and one differed by a single interchange. The genom giving 7 pairs with [h]*hookeri* has been designated as α *Hall 30*. Crossed with *Hall 21*, an F_1 was obtained in which both 7 pairs and $\odot$ 4 were again found. Obviously, it is the β genom of *Hall 30* which gives 7 pairs with [h]*Hall 21*, since the

latter gives ⊙ 4 with *ʰhookeri*. The genoms of *Hall 30*, therefore, are α *Hall 30*, with the segmental arrangement of *ʰhookeri*, and β *Hall 30*, with the arrangement of *ʰHall 21*, *excellens*, etc.

Hall 34.—In one plant of the first generation, 7 pairs plus a fragment were found; 2 plants had ⊙ 4; 2 plants had 2 ⊙s 4; and 1 plant had ⊙ 6. The plant with ⊙ 6 became parent of the following generation, as well as of all crosses involving this race. Crossed with *ʰhookeri*, plants were obtained with 7 pairs and also with ⊙ 6. Obviously, one genom (α *Hall 34*) has the same segmental arrangement as *ʰhookeri*. The segmental arrangement of β *Hall 34* cannot as yet be determined with certainty, for in no cross except to *ʰhookeri* has a configuration been obtained which could clearly point to this genom as present. Thus, ⊙ 4 was obtained in *Hall 21* × *Hall 34*, *Hall 34* × *Devil's Gate*, *Hall 34* × *Mateo* and *Hall 34* × *Mono* (8 pairs; ⊙ 4, 6 pairs, in this case); since, however, certain segmental arrangements which will give ⊙ 6 with *ʰhookeri* can also give ⊙ 4 with *ʰHall 21*, it is not unlikely that certain plants resulting from these crosses had β *Hall 34* in them.

Heusi.—Two plants of the first generation had 2 ⊙s 4, and 1 plant had ⊙ 4. The plant with ⊙ 4 became the parent of the next generation, and was used mostly in crosses. However, a plant with 2 ⊙s 4 was used in some crosses. When the plant with ⊙ 4 was crossed with *Devil's Gate*, *Hall 21* and *Mateo*, some plants with 7 pairs were obtained. One of the genoms of this *Heusi* plant had, therefore, a segmental arrangement like *ʰDevil's Gate* and *excellens* (called α *Heusi*). On the other hand, when crossed with *grandiflora*, one of the genoms gave 7 pairs with *acuens* (which gives ⊙ 4 with *ʰDevil's Gate*). Therefore, the β *Heusi* genom must have the segmental arrangement of *acuens*, namely,

$$1 \cdot 4 \quad 3 \cdot 2 \quad 5 \cdot 6 \quad 7 \cdot 10 \quad 9 \cdot 8 \quad 11 \cdot 12 \quad 13 \cdot 14$$

The plant with 2 ⊙s 4 was capable of producing in all probability 4 classes of genom from the standpoint of segmental arrangement. Two of these were probably α *Heusi* and

β Heusi, it being probable that the plants in question differed from the plant with ⊙ 4 in having suffered an additional interchange. If 2 of the possible genoms were *α Heusi* and *β Heusi*, the remaining might be designated as *γ* and *δ Heusi*. They are defined as follows: *γ Heusi* is the arrangement (see formulae below) which will produce ⊙ 4 with *β Heusi* and 2 ⊙s 4 with *α Heusi*. It must therefore have 1·4 and 3·2, and differ from *α* and *β Heusi* in respect to 2 of the remaining 5 chromosomes. *δ Heusi* is the arrangement which will produce ⊙ 4 with *α Heusi* and 2 ⊙s 4 with *β Heusi*. It must therefore have 1·2 3·4, and differ from *α* and *β Heusi* in respect to the same 2 chromosomes.

When *Heusi* (2 ⊙s 4) is crossed with *Hall 30*, one of the configurations obtained in F_1 is ⊙ 4, ⊙ 6. This could not be obtained by combining *α* or *β Heusi* with either *α* or *β Hall 30*. Nor could it be given by *δ Heusi*, which must have 1·2 3·4, and therefore, in order to give ⊙ 4, ⊙ 6 with *α Hall 30*, would have to give as part of its configuration with *α* or *β Heusi* ⊙ 6. The configuration ⊙ 4, ⊙ 6 must have been produced by the union of *γ Heusi* and *α Hall 30*. In order to give ⊙ 4 with *β Heusi* and 2 ⊙s 4 with *α Heusi* and still give ⊙ 4, ⊙ 6 with *α Hall 30*, *γ Heusi* must have one chromosome in common with *α Heusi* which it does not have in common with *α Hall 30*, namely, 7·10 or 9·8, and *δ Heusi* must therefore have the same. For the sake of illustration, we may give them 7·10, and select 11·12 as the chromosome which has interchanged with 9·8. Formulae may then be written as follows:

$$\alpha\ Heusi = 1\cdot2 \quad 3\cdot4 \quad 5\cdot6 \quad 7\cdot10 \quad 9\cdot8 \quad 11\cdot12 \quad 13\cdot14$$
$$\beta\ Heusi = 1\cdot4 \quad 3\cdot2 \quad 5\cdot6 \quad 7\cdot10 \quad 9\cdot8 \quad 11\cdot12 \quad 13\cdot14$$
$$\gamma\ Heusi = 1\cdot4 \quad 3\cdot2 \quad 5\cdot6 \quad 7\cdot10 \quad 9\cdot12 \quad 11\cdot8 \quad 13\cdot14$$
$$\delta\ Heusi = 1\cdot2 \quad 3\cdot4 \quad 5\cdot6 \quad 7\cdot10 \quad 9\cdot12 \quad 11\cdot8 \quad 13\cdot14$$

It must be noted that these selections are purely arbitrary, and are chosen from a number of possible alternatives. The selection made is not meant to be used in the definition of these chromosomes; the arrangement here given is for illustrative purposes only.

The *Heusi* individual with 2 Cs 4 was crossed with *Hall 30*, *Hall 34* and *Mono* (C 4). In most cases it was not possible to decide which of the *Heusi* genoms was present in F_1 plants with a given configuration. The possibilities are listed in table 2.

The segmental arrangements of the genoms present in the various California forms included in this study, so far as they have been worked out, are as follows:
ᴴhookeri, ᴴfranciscana deV., *α Hall 30, α Hall 34*

$$1 \cdot 2 \quad 3 \cdot 4 \quad 5 \cdot 6 \quad 7 \cdot 8 \quad 9 \cdot 10 \quad 11 \cdot 12 \quad 13 \cdot 14$$

ᴴDalton, ᴴDevil's Gate, ᴴJohansen, ᴴHall 21, ᴴMateo, ᴴMono, α Heusi, β Hall 30, ᴴfranciscana E & S

$1 \cdot 2$	$3 \cdot 4$	$5 \cdot 6$	$7 \cdot 10$ $9 \cdot 8$	$11 \cdot 12$	$13 \cdot 14$
β Heusi $1 \cdot 4$	$3 \cdot 2$	$5 \cdot 6$	$7 \cdot 10$ $9 \cdot 8$	$11 \cdot 12$	$13 \cdot 14$
γ Heusi $1 \cdot 4$	$3 \cdot 2$		$7 \cdot 10$ or $9 \cdot 8$		
δ Heusi $1 \cdot 2$	$3 \cdot 4$		$7 \cdot 10$ or $9 \cdot 8$		

In conclusion, it should be emphasized (1) that the great majority of California genoms involved in this study have one of two segmental arrangements, either that of *ᴴhookeri*, or that of *ᴴDalton*. Of the two, the latter has proved so far to be the more frequent, so that the arrangement of *ᴴhookeri*, which has been used, and will continue to be used as the standard, seems to differ from the arrangement most commonly found in the California assemblage by one segmental interchange. (2) The findings presented in this paper with reference to chromosome configurations are in every respect in harmony with the segmental interchange theory of circle formation. Wherever it has been possible to anticipate in whole or in part the configuration of a hybrid on the basis of known facts regarding the segmental arrangements of the parents or of other crosses, the anticipated configuration has been obtained. The number of such cases is so large as to preclude any possibility of error in the assumption that segmental interchange has been responsible for circle formation in *Onagra*.

Summary

Nine distinct strains of *Onagra* from widely diversified habitats in California are described on the basis of their characteristics as shown in the experimental garden. Many crosses have been studied involving (*a*) California strains as both parents, (*b*) California strains with races from other regions; these are briefly characterized. The behavior of certain phenotypic characters is discussed; one of these characters, erect marginal hairs, is ascribed to a single recessive gene, *e*. Chromosome configurations have been determined for all strains and practically all hybrids.

The California strains as a whole have been found to be exceptional within the sub-genus *Onagra*, in that they show little evidence of those peculiarities, cytological and genetical, which have brought this group into such prominence. They give no evidence of the presence of lethals; they do not form the sort of gene-complex so characteristic of the group as a whole; in general, they appear to be less heterozygous than most of the forms from other regions, some of them being apparently entirely homozygous; they do not show large circles of chromosomes, but have mostly paired chromosomes. In short, they are not to be classed with the "complex-heterozygotes" of Renner, which have dominated the *Onagra* picture up to the present; they approach, rather, the more usual type of cyto-genetic behavior characteristic of most families and genera of plants.

Hybrids between California strains also show for the most part paired chromosomes, showing that the segmental arrangements of the various strains are identical or nearly so. It appears, therefore, that there is a certain type of segmental arrangement which is characteristic of the California group as a whole. When crossed with forms from other regions, the California races give hybrids which show among them every condition with respect to chromosome configuration from entirely paired chromosomes to entirely concatenated chromosomes. It is significant that some complexes belonging to extra-California races have segmental arrangements

of the California type, although most have quite unrelated arrangements.

These findings are discussed in the light of the hypothesis, developed in earlier papers, that relative similarity of segmental arrangement means in general a relatively recent divergence from a common ancestral source. and therefore a relatively close relationship between the complexes concerned; whereas relative dissimilarity of segmental arrangement means in general a more distant relationship. On the basis of this hypothesis, the California group appears to be a tightly knit assemblage of closely related forms. Furthermore, the genoms belonging to extra-California forms which are segmentally of the California type are. by the same token, in all probability closely related to each other and to the California assemblage. Since the type of segmental arrangement represented by these genoms is preeminently characteristic of the California forms. it seems that California must be regarded as a center of distribution which has contributed, to some extent at least, to the development of the *Onagra* population in other, and often distant. regions. The question as to how races from other regions than California have in some cases come to be composed of a genom of the California type, associated with a genom which is not of the California type, is discussed.

A program of future investigation is suggested, with the object of determining the actual incidence and the importance of the California-type of genom in all parts of the range, as well as ascertaining the affinities and origins of the complexes which are not of the California type. As the affinities of the various races of *Onagra* become by these means increasingly apparent, it should be possible more and more accurately to evaluate the roles which various factors have played in the evolution of the group. thus affording a clearer insight into evolutionary processes in general.

LITERATURE CITED

CLELAND, R E., 1928. The genetics of *Oenothera* in relation to chromosome behavior, with special reference to certain hybrids. Proc. 5th Intern. Congr. Genetics; Zeitschr f. indukt. Abst. u. Vererb.. Supplementband 1: 554–567.

——, 1931. Cytological evidence of genetical relationships in *Oenothera*. Amer. Jour. Bot. 18: 620–640

—— —, 1932. Further data bearing upon circle-formation in *Oenothera*, its cause and its genetical effect. Genetics 17: 572–602. 1932.

—— AND A. F. BLAKESLEE, 1931. Segmental interchange, the basis of chromosomal attachments in *Oenothera*. Cytologia 2: 175–233.

—— AND F. OEHLKERS. 1929. New evidence bearing upon the problem of the cytological basis for genetical peculiarities in the *Oenotheras*. Amer. Nat. 63: 497–510.

EMERSON, S. H., 1929. Multiple-factor inheritance in crosses between *Oenothera grandiflora* and *Oe. franciscana*. Papers of Mich. Acad. Sci., Arts and Lett. 9: 121–138.

——. 1931. Genetic and cytological studies on *Oenothera* II. Certain crosses involving *Oenothera rubricalyx* and *Oenothera "franciscana sulfurea."* Zeitschr. f. indukt. Abst. u. Vererb. 59: 381–394.

——, AND A. H. STURTEVANT. 1931. Genetic and cytological studies on *Oenothera* III. The translocation interpretation. Zeitschr. f. indukt. Abst. u. Vererb. 59: 395–419.

HOEPPENER, E., u. O. RENNER. 1928. Genetische und zytologische Oenotherenstudien I. Zur Kenntnis der Oenothera ammophila Focke. Zeitschr. f. indukt. Abst. u. Vererb. 49: 1–25.

MULLER, H. J., A. PROKOFYEVA AND D. RAFFEL, 1935. Apparent gene mutations due to the position effect of minute gene rearrangements (Abstract). Amer. Nat., 69 (1).

OEHLKERS, F., 1921. Vererbungsversuche an Oenotheren I. *Oenothera Cockerelli* Bartlett und ihre Kreuzungen. Zeitschr. f. indukt. Abst. u. Vererb. 26: 1–31.

——, 1926. Erblichkeit und Zytologie einiger Kreuzungen mit *Oenothera strigosa* (Vererbungsversuche an Oenotheren IV). Jahrb. wiss. Bot. 65: 401–446.

RENNER, O., 1925. Untersuchungen über die faktorielle Konstitution einiger komplexheterozygotischer Oenotheren. Bibliotheca Genetica 9: 168 pp.

—— AND R. E. CLELAND, 1933. Zur Genetik und Cytologie der *Oenothera chicaginensis* und ihrer Abkömmlinge. Zeitschr. f. indukt. Abst. u. Vererb. 66: 275–318.

STURTEVANT, A. H., 1931. Genetic and cytological studies on *Oenothera* I. Nobska, Oakesiana, Ostreae, Shulliana, and the inheritance of old-gold flower color. Zeitschr. f. indukt. Abst. u. Vererb. 59: 365–380.

DE VRIES, HUGO. 1914. L'*Oenothera grandiflora* de l'herbier de Lamarck. Rev. Gen. Bot. 25: 151–166.

THE ALPS IN HISTORY

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(Read April 18, 1935)

THE story of the Alpine chain which separates Italy from
the areas to the north is long and eventful. Its history,
beginning with the gradual expansion of the Romans to the
foothills and beyond in the late Republic, covers a period of
well over two millennia. Further back we may even glimpse
something of its prehistoric use as disclosed by archaeology,
mythology, and historical inference. For from time im-
memorial the Alps have been crossed, and never have formed
an impassable barrier either to plants, animals or men.

Thus neolithic settlements can be traced along the entire
course of the Brenner in the Eastern Alps—one of the oldest
passes. The early use of the coast-route along the Riviera
from Southeast France to Genoa is attested by the myth of
the Ligurian King Cycnus in connection with the prehistoric
amber-trade southward to the Mediterranean from the North
Sea. Similarly, the early use of the Little St. Bernard from
France into Val d'Aosta can be inferred from its ancient
name—*Alpis Graia*—which the Romans, ever bad etymolo-
gists like the Greeks, translated as the "Greek" pass, over
which they believed that Hercules, the first mortal to cross
the Alps, found his way. Some of the eastern passes, notably
the Brenner and Birnbaumerwald, because of their moderate
heights, served as gateways through which many folk-
wanderings reached Italy from Central and Eastern Europe
long before Italy was guilty of Rome. In this way the earliest
Indo-European invaders of Italy, the Terramara peoples, must
have reached the valley of the Po from the Save and Drave,
and ultimately the Danube, bringing with them the rudiments
of Italian culture and a speech which was the forerunner of

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Latin. Thus these eastern passes played a rôle in the beginning of Italian culture as well as in its final downfall, since it
was chiefly over them that the barbarian invaders crossed
centuries later to overwhelm Italy and destroy the Western
Empire, and old Rome was no more.

The first mention of the Alps in European literature is by
the Greek historian Herodotus, who wrote in the middle of the
fifth century B.C., but to him *Alpis* was a river, a tributary of
the Danube.   A century later Aristotle called the chain by its
earliest known name—whether Celtic or Germanic—the
"Arcynian Mountains," a name recalling that of the Hercynian Forest which anciently spread over a great section of
South Germany.   But we do not meet the name *Salpeis* till
the third century B.C., in the work of the little-known Alexandrian poet Lycophron.   Curiously we do not yet know with
certainty the origin of the name.   The Romans naturally
connected it with *albus*, but more probably the name is
Celtic for "lofty," as it appears still in Gaelic *alp* and Erse *ailp*.
And we know that the Celts or Gauls occupied both slopes for
centuries, having reached Italy from the Tyrol by the Brenner toward the close of the fifth century B.C., their settlements
finally covering the valley of the Po so that throughout Roman times North Italy was known as Cisalpine Gaul.   Even
yet remains of Celtic speech are found in the southern foothills.

Two centuries after the unheralded coming of the Celts
occurred the most spectacular transit of the Alps in ancient
or modern times, that of Hannibal and his elephants over a
western pass in the fall of 218 B.C.   In fact it was his crossing
which first aroused the Romans to an active interest in their
northern barrier, and it was his traverse far more than his
supreme military genius which has left so indelible a memory
on posterity.   Thus the identification of his pass has been the
subject of endless discussion in our times, when all sorts of
books, ranging from technical to semi-romantic, have been
written on this theme from the historical, topographical,
military, meteorological and economic points of view.   And it
is certain that the vexed question will continue to intrigue

investigators since the data available are insufficient to render
a decision agreeable to all.

In the following century the Romans were attracted to the
foothills by the mineral wealth of the Celts, especially the
gold of the Salassi in Val d'Aosta and the iron of the Taurisci
in the Tyrol beyond the Eastern Alps. The Roman mer-
chants here, as later in Gaul, preceded the Roman soldiers,
but the legions were sure to follow. Soon they came to
repel invaders—first the Cimbri and their kinsmen the
Teutones, the earliest barbarian hordes from the northland
who came in historic times in search of a southern home.
After spreading terror for years in Gaul, Spain, and Switzer-
land, and after beating many consular armies beyond the
Alps, they finally were destroyed by Marius—the Teutones
on the Rhone above Marseilles in 102 B.C., the Cimbri the
following year near Verona in Italy which they had reached.
It was their German kin who, centuries later, exacted a
terrible vengeance, when in successive waves they poured
over the Alps and ended the Western Empire.

Still later the Romans came as conquerors and adminis-
trators of the Alpine tribes and areas farther north. In
consequence of Caesar's Gallic Wars, they felt the need of
subduing the mountaineers in order to control the pass-routes
into Gaul and Helvetia. Caesar's plans, cut short by his
assassination in 44 B.C., were carried out by his grand nephew,
known to us as Augustus, the founder of the Roman Empire.
In a desultory war begun around 25 B.C., but whose major
operations were completed in 16–14 B.C. by the emperor's
stepsons, Tiberius and Drusus, the entire chain became a
part of the Roman state.

Augustus' victory over the mountain tribes was com-
memorated by a trophy in the form of a three-storeyed
tower the ruins of which—restored only last year—still over-
look the blue waters of the Mediterranean at La Turbie
(the name is a corruption of Latin Tropaeum) near the sum-
mit of the Roman coast-road above Monaco, now a part of
Napoleon's *Grande Corniche.* Its weatherbeaten inscription

names forty-eight tribes then subjugated, while eight others
are known from a smaller trophy set up at Susa on the Mt.
Genèvre route. Augustus further boasts on the famous
Monumentum Ancyranum, lettered in Greek and Latin on the
walls of a ruined temple at Angara in Anatolia, now the capital
of the Turkish Republic, that "the war brought injury to
none." Yet he had caused thousands to be slain and thou-
sands more to be driven into slavery, all because they had
fought the good fight of freedom.

By the close of the war the founder of the Empire held
both sides of the Alps, and he and his successors erected
provinces to the north, expanding Roman power eventually
all the way from the North to the Black Sea. Only one
monarch since, Charlemagne (768–814), has controlled the
entire chain, for not even Napoleon gained the eastern section.
Today the Alps are shared by six nations—Italians, French,
Swiss, Germans, Austrians, and Jugo-Slavs.

The cultural activity thus started by Augustus was even
more remarkable than the conquest—the gradual Romaniza-
tion of a vast area, a process which continued to the
close of the Empire. Yet more, for that concerns ancient
history only, for then was started a movement which lasted
on through the medieval period down to the fifteenth century,
during which the basis of the states of Modern Europe was
being laid. This was Augustus' unwitting gift to the modern
world.

The conduits of this cultural movement were the Alpine
roads which Augustus and his successors built to connect
Italy with the north. Along these highways in the valleys
below flourishing towns arose. Today most of the important
towns as far north as the Rhine and Danube are on Roman
sites. In Switzerland alone nearly every large town is on a
Roman or earlier Celtic base.

Curiously the Romans from the time of Augustus onward
instituted no new routes across the Alps, but were content to
improve the ancient trails long before used by Celts and their
prehistoric predecessors. In all Augustus appears to have

built eight roads along these ancient trails: those along the
Riviera from Genoa west; over the Mt. Genèvre, a restoration
by his prefect Cottius of an older road built in 77 B.C. by
Pompey; across the Little St. Bernard, similarly a restoration
of the Gracchan road built in 122 B.C., and so the oldest in the
Alps; over the Brenner from Verona as far as Trent; the
Ploecken route from Aquileia to Trent and the Birnbaumer-
wald road from Aquileia to Oberlaibach on the Save, later
extended as the "Pannonian Highway" to Carnuntum on the
Danube; and in all probability those over the Maloja and
Julier in the Central Alps, connecting the Val Bregaglia in
Italy and Coire in the Engadine.

Later emperors repaired these roads or built anew over
other ancient trails. Thus Claudius in the first century con-
structed a road from Venetia through the Valsugana to the
Brenner and beyond over the Reschen-Scheideck and Fern
Passes to the Danube, and another over the Great St. Bernard
from Aosta to Martigny on the Upper Rhone. The Severi
between 195 and 215 built the first military road across the
Brenner and the Scharnitz Passes from Trent to Innsbruck
and on to Augsburg in Germany.

Remains of these ancient roads are visible in many parts
of the Alps—roadways, pavements, wheel-ruts, inscribed
rock-walls, and countless milestones. There are even ruins
of refuges—one 216 by 60 feet, dating from the Later Empire
on the summit of the Little St. Bernard, discovered in 1837
by a party of English tourists, and another still larger, 200
feet square, found more recently three-quarters of a mile
beyond. A ruined *mansio* has also been found on the summit
of the Great St. Bernard along with the remains of a temple of
Jupiter—the latter the highest in the Roman Empire. There
are many rock-cuttings against wind and snow, one 200 feet
long and 10 feet wide on the summit of the Great St. Bernard.

Recently I followed two stretches of ancient roadway on
the northern ascent of the Radstaedter-Tauern Pass in
Austria—one, high above the modern road, which runs along
the river, the other a mile long nearer the summit. Perhaps

the best preserved remains of roadway are those between Haidenschaft and Oberlaibach on the Birnbaumerwald route, but the most imposing are those just outside the hamlet of Altino, the beginning of the *Via Claudia Augusta*—now locally known as Agozzo—where the pavement is twenty metres broad. The best example of wheelruts which I have seen is above Tweng on the southern ascent of the Radstaedter-Tauern, where through a defile between the present highway and the river in a pavement of glistening white marble the ruts are from four to five inches deep.

There is still another reminder of the ancient Alpine roads —the coins which have been found along them recalling the Roman custom of propitiating or thanking the local god for a safe transit. The monks of the Great St. Bernard have garnered over 1,600 such coins in the monastery museum, which date from 150 B.C. to the barbarian invasions in the fifth century. On the summit of the Julier in a hole at the foot of one of the two so-called Julier columns—Roman or Celtic in origin—a mass of copper coins was found whose dates span the four centuries from Augustus to Constantius II. The most curious *cache* of all, however, was on top of the St. Theodule, a pass over two miles high leading from the Italian Val Tournanche to Zermatt, which I crossed in 1929. A maid from the Old Hospice in 1895 found here in the ice a hoard of 54 coins dating from Nerva to Theodosius the Great, a period of 300 years. As there never has been a road over this pass ancient or modern, such a find is hard to explain. Perhaps a few intrepid merchants dared the glaciers as smugglers do to-day, and left the coins in gratitude.

We must not confuse these Alpine roads with the great turnpikes running straight to their goals over hills and valleys which we are accustomed to associate with the Romans—the greatest of road-builders, for the Alpine sections were far simpler, mere connecting links between the great highways far below. Nevertheless, they formed integral parts of the network of roads which once radiated over Western and Southern Europe, and far into Asia and North Africa.

Descriptions by various classical writers, both Greek and Roman, show us that the difficulties of crossing such mountain roads—caused by overhanging rocks, steepness, avalanches, crevasses, and snow—were then far greater than those which confront travelers in the Alps today. No wonder, then, that the Romans felt an aversion to the Alps. Their interest remained always practical, for the mountains were merely obstacles to be overcome in their expansion. Only merchants, officials, and soldiers crossed them and never for pleasure, for the Romans never developed any sentimental interest in their scenery, inhabitants, languages, customs, flora or fauna. As a typical illustration of this it is said that the greatest of the Romans, Julius Caesar, once while crossing the Mt. Genèvre to his army in Gaul composed an essay on *Analogy* in his curtained litter quite oblivious of the scenery.

Nevertheless the Romans overcame their dislike enough to build roads over most of the major passes yet in use to-day. Thus of the seven over the Western Alps they knew all except the Mt. Cenis and Simplon; of the nine over the Central Alps, all except the St. Gotthard, Lukmanier and Bernina; and of the seven over the Eastern Alps they seem to have known all except the Stelvio. This gives us a total of seventeen major passes out of twenty-three now in use. And they knew about as many minor ones as well. This seems a small number when compared with the great array of passes, major and minor, now in use, of which the Britannica lists 518 throughout the Great Divide.

Throughout the Middle Ages—that indeterminate period of over a thousand years from the passing of Rome to the bloom of the Renaissance, or, perhaps, to the crisis of the Reformation—the Roman roads over the Alpine passes were still used. In fact, we have records of very few new routes during that period.

Thus we first hear of the Mt. Cenis in a document of 731, and we know that its hospice, one of the oldest medieval ones in the Alps, was founded by Louis le Débonnaire or his son

early in the next century. The St. Gotthard, one of the
grandest of all, leading from Bellinzona in Italy to the Lake
of Lucerne, was known to the Romans as far as Andermatt
beyond the summit, but their way farther north was barred
by the Schoellenen Gorge through the vertical granite walls of
which the brawling Reuss descends. Not until the chasm
could be spanned by a bridge was it possible to reach the
northern exit of the pass, and the first "Teufelsbruecke" was
not built till around the year 1200. The Lukmanier, after the
Maloja the lowest and easiest pass from Switzerland to Italy,
is known from the records of its famous abbey at Disentis
from 776, and the first recorded transit was that of the Holy
Roman emperor Otto the Great in the winter of 964–5.

It is indeed a matter of wonder that throughout the medie-
val period so few new routes were opened and so few of the
Roman roads were kept in repair. Various reasons for this
have been adduced—especially lack of capital and division of
authority among local powers, each responsible for its own
section only. But probably the main reason is to be found
in the lack of labor to replace the Roman slaves. A recent
historian has said that not one Holy Roman emperor imitated
his pagan predecessors, the Caesars, either by building a
new road or improving any of the old ones which they had
inherited!

What had happened? We know that in the gradual dis-
solution of the Roman Empire after the death of Constantine
the Great in 337, trade everywhere waned, for with the
spread of Christianity religion usurped commerce as the
chief interest of the Middle Ages. This change was, of course,
reflected in the Alps as everywhere else. Now the merchants
of an earlier day were replaced by pilgrims and ecclesiastics
on the way to and from Rome, "the threshold of the Apostles."

That the medieval traveler faced much the same difficulties
in crossing the Alps as his pagan predecessor is shown by three
contemporary descriptions of transits of the Mt. Cenis and
Great St. Bernard in the eleventh and twelfth centuries.
These dangers, apart from the usual weather conditions, were

lack of food and refuges, and, above all, the presence of robbers. Christian hospices, however, gradually replaced the Roman *mansiones*. Many of these have been restored or rebuilt and have survived to our time, notably the two famous ones founded by St. Bernard in the eleventh century, on the summits of the passes which still go by his name.

In modern times the Alpine passes have played an ever increasing role in war and commerce, and, more recently, also in recreation. The latter is true of the last century during which splendid highways have been built across all the main passes, and since 1900 automobiling over them for pleasure has become common.

There have been many historic transits of the Alps by armies in the last four centuries, beginning with that of the youthful Francis 1st who, with an army of 20,000 men and 75 cannon, crossed the Col de l'Argentière from Grenoble to Italy in August 1515, prior to the "moonlight" battle of Marignano, where the French arquebus proved superior to the pikes of the Papal troops.

Such transits followed the old medieval-Roman roads down to the time of Napoleon, before whom little road-building in the modern sense was known in the Alps. To be successful such construction required the use of powder to break the rock, and it is curious how slowly it came into use. We first hear of "powder-blasts" toward the end of the Middle Ages in connection with "Kunter's Way," a two-mile section of the Brenner built in the fourteenth century. Again in the fifteenth, between 1481 and 1483, Duke Sigmund of Tyrol built another section of the same pass-route by splitting the rock with "fire, sulphur, and iron." But powder on an extensive scale was first employed in 1697 in the construction of a rock-hewn road through the Berguen Gorge of the Albula, and we hear little more of its use for a century thereafter.

It was Napoleon, then, who, during his temporary hold on Switzerland and North Italy, gave the modern impetus to Alpine road-building, an impetus comparable with that of Augustus eighteen centuries before. For, during his transit

of the Great St. Bernard in the spring of 1800, he experienced
the difficulties of transporting an army over a lofty pass
without a good road.   His artillery was then as badly im-
peded by natural difficulties in ascending the Valsorey Gorge
—up which his cannon had to be dragged encased in hollow
logs—as Hannibal's elephants had been.

Between 1800 and 1810 Napoleon built four military roads
across the Western Alps: the coast-road from Nice to Genoa,
including the *Grande Corniche* to Mentone, and those over the
Mt. Genèvre, Mt. Cenis, and Simplon.   Curiously he did not
build one over the Great St. Bernard, where a modern road
was not completed on the Swiss side till 1893, and on the
Italian, including the connecting link over the top, till 1905.
He also began a road over the Col de l'Argentière, and planned
still another over the lofty Umbrail far to the east, which was
not finished till three years after his death on St. Helena,
and was restored between 1899 and 1901.   Before the 1830's
were over many other pass-roads had been built—notably
those over the Julier, San Bernardino, St. Gotthard, and, high-
est of all, the Stelvio.

In the modern period only a few major pass-routes have
been opened, even fewer than in the medieval.   Perhaps
the best example is that over the Stelvio on the borders
of the Central and Eastern Alps.   Here the Austrian Govern-
ment constructed a military road in 1820–1825 as a feeder
into the Umbrail route then being built.   Its construction was
a continuous struggle with snow and ice at a height theretofore
open only to expert climbers, an astonishing work of engineer-
ing skill.

Railways over the passes began with that across the Sem-
mering in Austria, built 1845–1854.   It was followed by one
over the Brenner in 1867, and that by the boldest and most
spectacular mountain-railway in the world, the one built
between 1872 and 1882 over the St. Gotthard.   This has 324
bridges and 80 tunnels—including the great one under the
pass to be mentioned—three of which are spiral in form on the
Swiss ascent and four on the Italian.

With mountain-railways began the piercing of the chain by tunnels. The first one beneath the Semmering Pass is a little less than a mile in length. To-day five great tunnels cut the Alps, three through the main divide, and two wholly within Switzerland and Austria respectively. The oldest is the so-called Mt. Cenis Tunnel, which runs beneath the Col de Fréjus, some seventeen miles southwest of the Mt. Cenis Pass, and connects Modane in France with Bardonnechia in Italy—a distance of eight miles with the approaches. It took fourteen years to build it, 1857–1870, and the engineering was so accurate that the borings begun simultaneously at either end joined almost exactly in the center.

The St. Gotthard Tunnel, connecting Goeschenen in the Schoellenen Gorge in Switzerland with Airolo in Italy, is nine and a quarter miles long, and required ten years, 1872–1881, to complete. The longest railway tunnel in the world is still the Simplon, over thirteen miles in length with its approaches. It has parallel tubes for one-way traffic. The culminating point of the tunnel is 4,270 feet below Napoleon's highway over the pass, and the encircling mountain crest above rises nearly 3,000 feet higher yet.

The automobile has long since found its way over the major passes and soon will have its own tunnel beneath Mont Blanc, the monarch of European mountains. Only last year plans were drawn for a motor-tunnel with double tubes to connect Chamonix with Entrèves near Courmayeur—a distance of eight or nine miles. The need of such an automobile route between France and Italy is evident from the fact that out of six existing Alpine roads across the frontier of 230 miles between them only one—the Riviera route—is open in winter.

This brief sketch of the story of Alpine roads has shown that the use of most of the major pass-routes has been continuous from prehistoric times to the present. Long before the advent of man in the Alpine solitudes Nature had marked

out just where such routes could go.   Their story, then, is
merely the gradual use man has made of the passes through-
out the ages.   Their number and location were fixed for all
time by the natural configuration of the Alpine chain.

DEMOCRACIES AND DICTATORSHIPS: THE DEBIT SIDE OF THEIR LEDGERS

ROBERT C. BROOKS

(Read April 18, 1935)

OF the making of many definitions of democracy there is no end. It is conceived not only as a form of government but also as a social system, as a way of life, even as a quality of manners. Various as are these definitions all of them derive from the political concept, first formulated in scientific terms by Aristotle. A similar development is now taking place in the case of dictatorships. Beginning primarily as forms of government each of them is now proclaimed by its protagonists to be a new social system, a new way of life, indeed in one case, that of Hitler's Third Reich, to be a new *Weltanschauung*.

It is a truism that no government exists *in vacuo*—or in a purely political medium for that matter. Each must be studied as affected by its environment, geographic and social, also by its historical background. Since, however, both democracies and dictatorships present themselves *ab origine* as types of government they must be considered first from this point of view, that is as purely political concepts. Due to limitations of space it is the primary purpose of the present discussion to examine the debit side of their ledgers. On positive grounds the presumption is strongly in favor of democracy. In spite of certain successes alleged to have been achieved recently by dictatorships it can be shown that they run counter to the processes of social evolution, and that they are devoid of sound ethical foundations.[1] Moreover the democracies of the world are still immensely stronger than the dictatorships—in population, resources, wealth, technological

[1] Daniel S. Robinson, *Political Ethics*, New York, 1935, chs. v, vi, vii.

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development, even in military strength.[1] If, then, as will be demonstrated in the following pages, the political disabilities of dictatorship are far greater than those of democracy, the strength of the case against the former on that score is beyond question.

As a form of government democracy in its purest sense is the direct, freely-exercised rule of all, each counting equally. Two things are of primary importance in the foregoing definition, the collective element expressed in the words "the rule of all," and the individualistic element, equalitarian in character. As to the former it must be admitted that no country has ever attempted to confer even the modicum of political power represented by the right to vote upon *all* the human beings resident in its territory; to that extent at least a pure democracy has never existed. Age qualifications have always been maintained, although the date line at which maturity is presumed to be reached has shifted from time to time in the past and may do so in the future. Citizenship, property, religious, racial and other electoral qualifications bulk large in the pages of history since 1789. Even in the most democratic countries of the world woman suffrage is a recent and by no means universal achievement.

It would, of course, be extreme to assert that no government has a right to call itself democratic until all those who live under it are given the vote. Nevertheless the first test to be applied in each case is the extent to which the population as a whole is enfranchised. In that respect England and the United States take precedence over France and Switzerland since so far the latter have stood out against woman suffrage. On the other hand the exclusion of colored citizens from the ballot box in our southern states by various means, whether legal or illegal, is frankly antidemocratic.

So far as the electoral test is concerned it is possible to state quantitatively the degree of democracy prevailing in a given country at different times. For example, only 6 per cent of

[1] For statistical details see article by Clarence K. Streit, "Democracy versus Absolutism: a World-Wide Survey," in the *New York Times*, November 25, 1934.

our population possessed the right to vote during the Revolution; at present it is possessed by from 40 to 45 per cent.[1] In the course of the century following the Great Reform Act of 1832, the British electorate increased from 4 to about 55 per cent of the population.[2]

At this point it is necessary to note a qualification regarding the extension of the right to vote, a qualification which applies with the same force to each of the other tests of democracy. While any addition to the electorate, no matter of what character, is a step toward pure democracy, still it may be a very unwise step to take under given circumstances. If, for example, the new voters are numerous and ignorant, the result is likely to be corruption, inefficiency and misgovernment, perhaps to such a degree that violent upheaval may be threatened. On these grounds Thomas Carlyle in his then famous but now forgotten essay, *Shooting Niagara and After*, predicted the immediate downfall of England as a consequence of the passage by parliament of the Suffrage Act of 1867. Many there are, especially south of the Mason and Dixon line, who still regard the Fifteenth Amendment to the Constitution of the United States as a colossal mistake; there are even a few who hold the same opinion of the Nineteenth Amendment. Historians differ in their judgments on such matters; undoubtedly, however, democrats have erred at times in making extensions of the suffrage too rapidly. All of which amounts to saying that a policy, or a whole polity for that matter, may be everything that is democratic and nevertheless be thoroughly undesirable. We who live in a democratic atmosphere need to remind ourselves of that fact frequently.

Even more important than the collective aspect of democracy embodied in the phrase, "the rule of all," is its equalitarian aspect, expressed as "each counting equally." Since human beings differ enormously in their individual capacities,

[1] J. Q. Dealey, *Growth of American State Constitutions*, New York, 1915, p. 150; see also the author's *Political Parties and Electoral Problems*, New York, 1933, pp. 389 et. seq.

[2] W. B. Munro, *Governments of Europe*, New York, rev. ed., 1931, p. 143.

political as well as otherwise, the objection may be raised that pure democracy is not attainable as between individuals any more than in its collective aspect. Also leaders are commonly said to be needed to an even greater extent under popular government than under aristocracies, monarchies or dictatorships. It is manifest, however, that leaders exert more power than do lieutenants or the rank and file of their followers. Confronted by the phenomena of machine rule in the United States, Theodore Roosevelt once sought to evade this difficulty by asserting that "a leader leads, a boss drives." Epigrammatic as the phrase is, the fact remains that leaders of both types use both methods of control to varying degrees. While relying largely upon persuasion, often in the form of jobs or political charity, the American political boss does use compulsion to a much greater degree than the type of leader Theodore Roosevelt had in mind. However, in this respect the most powerful of our bosses is a mere tyro as compared with the typical contemporary dictator. As a basis for differentiating democracy and dictatorship, therefore, the Rooseveltian dictum is not without validity.

While complete equality of political influence as between individuals is practically unattainable even under the most democratic system, still efforts can be made to achieve it in some degree. Here again one must concede that such efforts may or may not be wise under various circumstances; in any event, however, they are democratic. "One man, one vote; one vote, one value" being the aim, it follows that any system conferring a larger degree of electoral power on some individuals than on others, *e.g.*, pocket boroughs, the former three-class election system in Prussia, the plural voting system of Belgium from 1893 to 1919, are undemocratic.

In a democracy the rule of all must be exercised freely. Negatively this means that dominance over government by limited groups must be excluded. Democracy "is based upon a fundamental distrust of any irresponsible elite." [1]

[1] C. E. Merriam, *Civic Education in the United States*, New York, 1934, p. 42. The remark quoted is made with reference to American democracy. Essentially, however it applies to all governments of this type.

Exclusiveness similar to the above is, of course, characteristic not only of pure popular government but also of any other pure form of government. A monarchy, for example, which falls partly under control of an aristocratic chamber or of a popularly elective house ceases to be absolute. On this test, as on the others already considered, no existing government is pure in type. Even dictatorships, as we shall see, make occasional obeisance to popular votes; while the gesture is largely perfunctory still it is democratic. Similarly the most advanced of popular governments contain admixtures of other character.

England's constitution, for example, is "veiled in monarchical forms," also there are in its organization certain "survivals of aristocratic privilege."[1] Nevertheless two fundamental facts, first, the supremacy of the House of Commons, and, second, the breadth of the electorate which chooses its members, make the government of that country one of the most democratic in the world. Half a century ago Sir Henry Maine pointed out numerous constitutional "dams and dikes," particularly the Supreme Court, erected to restrain popular power in the United States.[2] Indeed it is to these anti-democratic institutions that he attributed our political stability as contrasted with the constant upheavals in France between 1789 and 1870, and in the so-called republics of South America after they threw off the Spanish yoke. Thus the legal institutions set up within the body of a popular government may have the effect of diminishing its democratic character. Extralegal institutions sometimes operate in the same way, e.g., party organizations under boss control, campaign funds contributed by wealthy citizens, pressure groups and lobbies seeking selfish advantages, a newspaper press owned by large corporate interests.

On its positive side free exercise of the rule of all means that the electorate must be able to organize, to carry on campaigns, to vote, to have its vote counted fairly, and to

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[1] Rephrasing the statement of L. Courtney, *Working Constitution of the United Kingdom*, New York, 1901, p. 3.

[2] *Popular Government*, London, 1885, ch. iv.

have it prevail—all without let or hindrance. Back of these primary conditions are others—freedom of speech and of the press, freedom of assemblage and petition, universal education for the duties of citizenship.

It would be erroneous to assume, however, that these liberties or any others which may be necessary to the operations of the electorate, are peculiar to a democracy. All forms of government must provide freedom of movement for the ruling power whether that power be monarchic, dictatorial, oligarchic or popular in character. The only thing peculiar to democracies in this regard is merely the extent of the body which bears power—the whole people or rather that large part of it comprising the electorate. Hence under a true popular government the right to act, and particularly to act freely, in political affairs must be made wide enough to cover the entire voting population.

But what of absolute liberty, of a sphere of action wherein the government must not interfere with the free choice of the individual or of groups of individuals? Such liberty is often referred to as a democratic principle; in point of fact it is not a principle of any form of government. If liberty in this sense be carried to its extreme, government disappears and anarchy—the term may be used either in its beneficent philosophical or maleficent popular sense—supervenes. Democracy, as pointed out above, is exclusive; whatever is removed from its control may fall under the domination of minority interests, which, whether selfish or otherwise, are always undemocratic. To that extent our "sphere of anarchy"—as the first ten amendments to the Constitution of the United States have been called—is a subtraction from popular control and hence a diminution of democracy. On this score the English government is a better example of democracy because its parliament possesses legal omnipotence and is subject to the will of the people.

After all liberty is associated with democracy not because of the essential nature of the latter but as the result of popular struggle against despotism in the late Eighteenth Century.

Subsequently, as Rousseau foresaw, democracy has proved quite as avid of power—always of course in the alleged interest of the whole people—as its predecessors, witness universal military training, abolition of slavery, compulsory education, progressive taxation, prohibition in the United States. On the other hand much of the dislocation in contemporary democracies is due to the liberty which so far they have permitted to powerful economic groups. Fundamentally, however, *laisser faire* is merely a policy, not a principle, of popular government. If democracy is true to its principle, if indeed it is to survive, it must take anarchic economic groups in hand by facilitating cooperation, by regulation, by industrial planning, even by measures of compulsion, ultimately, perhaps, by government ownership and operation. Neither does this necessarily mean dictatorship. Governments of the latter type destroy all forms of liberty; not only do they take away in effect the free participation of the people in government, they also abrogate all personal rights that stand in their way. Democracies are bound in principle to maintain the former; they restrict the latter, when necessary, by popular mandate.

In the last analysis therefore it is not liberty, but equality which is the basic concept of democracy. Equality is the goal; it is also, together with the "exclusive direct rule of all," part of the method—one vote, one value—to that goal. Since equality in the political sphere alone would be likely to atrophy, democracy is compelled to seek its extension in other fields, moral, educational, racial and social, above all at the present time in the economic field. It is committed not only to mass control but also "to the principle that the gains of civilization are essentially mass gains and should be distributed throughout the mass without too great delay." [1] Hence the general tendency of democracy in the past toward the extension of the suffrage, free public education, religious toleration, abolition of slavery, woman suffrage and feminism; neither is the later development within its midst of socialistic tendencies in any sense accidental.

[1] C. E. Merriam, *op. cit.*, p. 42.

Finally pure democracy is direct: in other words it must undertake to do everything possible by the immediate application of popular power. Here again of course the ideal is never fully realized; it is indeed unrealizable, as Eighteenth Century theorists were always pointing out, except by very small and very simple states. In practice Switzerland with its *Landsgemeinden* and town meetings, with its sweeping application of the Initiative and Referendum, goes farthest in this direction. For similar reasons our own state and municipal governments are, as James Bryce pointed out,[1] more democratic than our federal government. So far the latter remains purely representative or republican, nevertheless as a result of the extension of the suffrage, the direct election of senators, and, more recently, the adoption of the Twenty-first Amendment by popularly elected conventions, it has become much more democratic than it was in 1789.

Democracy may count itself fortunate in that it has never lacked critics—monarchists and aristocrats of the Old Regime whom it supplanted, then philosophers and politicians of extreme right or left tendencies, and nowadays advocates of Fascist or Communist dictatorships. Of the evils of pure democracy not much can be said; like Christianity it has never been tried. It is easy, however, to summarize the numerous and often contradictory charges made against the approximate democracies of the practical world—England and the Dominions, the United States, France, Switzerland, Belgium, Holland and the Scandinavian countries. To quote their detractors, the rule of all which they profess is a sham; their electorates are seduced by slogans, bamboozled by propaganda, bedeviled by demagogues, misled by corrupt parties, and exploited by swarms of practical politicians and crooked lobbyists most of whom are in the pay of corporate interests. So wide is the extension of the suffrage that it includes large numbers of the poor and ignorant who turn their modicum of political power to advantage by selling their votes or, more commonly nowadays, by becoming

[1] *American Commonwealth*, New York, rev. ed., vol. i, ch. xxxviii.

recipients of charity at the hands of the machine.   If balked
in the pursuit of these small material advantages they fall
prey to radical rabble-rousers, thus disturbing legitimate
business and threatening the established order.   However,
large financial interests by means of campaign contributions
and corruption funds manage to arrange some sort of *modus
vivendi* with demagogues and proletarian agitators, thus
transforming the alleged democracy into a masked plutocracy.
Nevertheless the mob impulse persists, hostile in every way to
blue-bloods and highbrows, levelling down all the distinctions
and elegancies of life to a dull mediocracy.   Popular educa-
tion has failed to improve matters; it is too superficial and the
I.Q. of the great mass is so low as to preclude any effective
degree of political training.   As a result of these major defects
and other minor ones too numerous to mention, democracy is
doomed.   If the particular prophet making this prediction
happens to be Fascist, the doom is Communism unless a
rescue is effected by his particular brand of dictatorship.   If
the prophet happens to be Communist, the doom of democracy
is equally certain, only the terms in which it is foretold are
transposed.

Parliamentarianism is subjected to a particularly heavy
barrage by the advocates of dictatorship.   While most of the
popularly governed countries named above have adopted
this system, it is not the only form in which the democratic
idea may be expressed.   As presidential in type and therefore
possessing a strong and more or less independent executive,
the United States differs from parliamentary countries and
escapes much of the criticism showered upon the latter.   One
suspects that our immunity from attack is due to purely
geographical circumstances.   Since neighboring democracies
in Europe are of the parliamentary type, advocates of dicta-
torship naturally unlimber their heaviest guns against it.
If these neighbors had been of the presidential type, the
defects of the latter, particularly separation of powers, check
and balance, would have been attacked without mercy.

In addition to all the common objections to democracy

cited above, critics of parliamentarianism condemn it because of the multiparty system, the constantly shifting majority blocs, the frequently falling ministries, the clash of innumerable pressure groups, and—above all—the resulting weakness of the executive branch and of the government as a whole. Hence the alleged necessity of a *Duce* or a *Führer* to rescue order out of the chaos misnamed parliamentary democracy.

Rebuttal of the foregoing is scarcely necessary in writing for a democratic public. As bearing upon certain phases of the recent history and the present condition of England, the United States, France, and other popularly governed countries of the world, some of the details of the indictment may need consideration; as a whole however, it is obviously not realistic portraiture but hostile and partisan caricature. One feature of the contemporary debate between democrats and advocates of dictatorship should afford the former much gratification. Stalin, Mussolini, Hitler and their small-fry imitators have now been in power long enough to make possible a thoroughgoing analysis of their achievements as contrasted with their earlier campaign promises, also as compared with the strictures they are accustomed to make against democracies.

Before undertaking such an analysis it is necessary to present the concept of dictatorship as clearly as possible. A dictator, according to the *Century Dictionary*, is "a person possessing unlimited powers of government; an absolute ruler." Dictatorship, then, is government under unlimited personal rule; by usage, however, the term does not include all cases of personal absolutism. Divine right monarchs, for example, have claimed prerogatives of the widest possible extent; nevertheless they may be distinguished from dictators on various important grounds. Moreover the historical concept of dictatorship has been revised fundamentally in recent practice.

The most striking difference between contemporary and earlier dictators is the permanence of power at which the former aim. Not only do Stalin, Mussolini and Hitler intend

to retain absolute authority for life, they also proclaim the immortality of the governmental systems over which they hold sway. According to the historical concept, on the other hand, the man called to be dictator was to function as such only during a temporary emergency, at the end of which his system—if one may dignify the brief exercise of absolute power by that term—was to give way to the form of government preceding his advent.[1] That this theory was practiced during the earlier Roman period is shown by the fact that "of the eighty-eight dictatorships between 501 B.C. and the decline of the institution three centuries later, most were for a very short period, six months at the longest."[2]

There is a sharp contrast between the argument by which dictators of earlier times justified their temporary lease of power and the argument by which contemporary dictators justify the permanence of their regimes. Neither is very convincing; nevertheless the differences between the two are illuminating in large degree. Dictators whether ancient or modern presuppose an emergency threatening the life of the state. Thereupon, according to the Roman theory, citizens voluntarily entrusted their liberties to a strong man in order that he might, as soon as normalcy was reestablished, return these liberties to them not less, possibly even greater, than before. On the whole a rather naïve plea since, as the later history of Rome showed, appetite grows by what it feeds on— an aphorism which applies with particular force to the appetite of dictators.

Contemporary dictators take the same starting point as their classic exemplars—an emergency threatening the life of the state. However they hold the existing dislocation to be so great and the government of the day so hopelessly incompetent that salvation can be attained only by a reconstruction of such fundamental character that an indefinitely long period of time will be required for its accomplishment.

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[1] An excellent statement of the classical theory of dictatorship may be found in Rousseau, *Social Contract*, bk. iv, ch. vi.

[2] See article on "Dictatorship" by Professor H. R. Spencer in the *Encyclopedia of the Social Sciences*, vol. v, p. 133.

Once accomplished it will prove so beneficent to the masses of the people that they would never dream of returning to the old order. In any event the political structure of the old order could not develop strength enough to maintain the reconstruction brought about under the dictatorship. Hence the necessarily enduring character of the process of escape and regeneration instigated by the latter.

A further argument, personal in character, is used in support of the permanence of the contemporary dictator. He is not likely to suffer from an unduly low estimate of his own capacities—megalomania is much more commonly indicated; also he is alleged to have saved the state from an emergency, the proportions of which may be so magnified as to appear absolutely catastrophic. Of course in seizing power he had the assistance of numerous devoted lieutenants and of a mass of followers, but adroit publicity men can easily shroud the deeds of the latter in the anonymity of the uniform shirt they wore—black, brown or what-not; meanwhile playing the spot-light constantly upon the laureled head of the one sublime hero. Thus the *Duce* or the *Führer* is built up to the proportions of a colossus bestriding the world, and by ceaseless propaganda through oratory, press and radio, the lesson is firmly imprinted upon the minds of his people that, having had the rare good fortune to be born under the star of a peerless leader, it would be rank ingratitude and stupidity on their part not to maintain him in life-long power and to perpetuate the system he has installed after his demise, world without end, amen.

Owing to their intended permanence it has been suggested that our contemporary dictatorships have forfeited that title, that it would be preferable to call them despotisms. Usage has decreed to the contrary; nevertheless comparisons between them and the absolute monarchies of earlier centuries are distinctly worth making. Both exemplify the principle of one-man power; they differ sharply, however, first, in that the old time monarchies provided for a definite line of hereditary succession—a problem not yet solved by contemporary

dictatorships; and, second, in that absolute monarchs claimed and enjoyed divine right whereas the dictators of to-day are secular persons who, moreover, seem to be chronically at odds with clerical authorities.

Of course the absolute power alleged to have been possessed by despotic kings—like all other absolutes in politics—must be taken with large reservations.   Comparatively few monarchs —Henry VIII, Peter the Great, Catherine the Great, Louis XIV, Frederick the Great—approximated such power.   It is significant that most of the crowned personages who succeeded in achieving a large measure of domination over their peoples were hailed as "the Great."   In spite of the theory of divine right the overwhelming majority of absolute kings were well aware of the presence of powers behind their thrones other than the deity who was made to stand sponsor for them. They had to take into account the interests of nobles and prelates, of army and bureaucracy, of landlords and money lenders, also in less degree the intrigues of courtiers and courtesans, of titular mistresses, ordinary mistresses, morganatic wives, even of intriguing legitimate wives—to say nothing of the swarms of soldiers of fortune, mercenaries, financial and medical quacks, official and unofficial diplomats, spies, pimps, lackeys, gamblers, blackmailers and astrologists who thronged their courts.   As a rule these elements carried on their intrigues silently and secretly; while they pulled the strings the monarch seemed to take action.   Hence it was easily possible to maintain the fiction of his omnipotence before a public largely illiterate and taught to obey implicitly by the priesthood.

Next to the reality of absolute power belief in its existence is a political asset of the highest value.   Contemporary dictators are quite as well aware of this fact as were the despots of the Eighteenth and earlier centuries.   All the resources of the controlled press and radio, of oratory and mass demonstrations are employed to magnify popular belief in the unlimited power of the *Duces* and *Führers* of to-day. Later in considering the question to what extent dictators

actually dictate, it will be necessary to note the sources of, and the restrictions upon, their power. Here it suffices to say that while free from many of the archaic forms of influence which were brought to bear upon absolute monarchs, they are compelled to deal with a variety of other more modern and more efficient kinds of pressure groups.

Present-day dictatorships run very grave risks because, unlike despotic monarchies of earlier centuries, they have failed to provide for a definite line of succession. Hence the likelihood of revolution at the death of the dictator; indeed, as the case of Primo de Rivera shows, revolution may not wait upon that event. A double risk is thereby incurred. The dictator comes in by revolution; in all probability his death will be followed by revolution. Of course one may cherish the pious hope that these upheavals will not be too bloody and devastating. Still the likelihood of two revolutions within the life-time of a single man, or perhaps within an even shorter period, is a rather formidable handicap for this type of government to carry.

Of the contemporary dictatorships in Europe one only— Soviet Russia—has survived a change in rulers. Upon Lenin's death in 1924, the hardboiled Stalin succeeded in overcoming his brilliant but too oratorical rival, Trotzky. In spite of the theoretical subtlety of the latter he lacked a strongly organized following and was quickly sent into exile by the Bolshevik analogue of a palace revolution. There was no civil war; no conflict occurred anywhere in Russia outside the higher circles of the Communist party, and even that was waged with words rather than with weapons. With this precedent in its favor the expectation of life of the Soviet dictatorship is perhaps better than that of any other government of the same type. Since his accession less than two and a half years ago Hitler has been so engrossed in efforts to consolidate his power that no formal provision for the choice of a successor has been made; however according to a news report of August 31, 1934, the German dictator personally favors Rudolf Hess.

Mussolini's utterances on this vital matter of policy have usually been characterized by a sort of egotistical skepticism. As late as 1932, he told an interviewer: "I think that there will not be a second *Duce;* or that, if he appeared upon the scene, Italy would not put up with him."[1] A more recent report, however, has it that upon the death, resignation or disappearance of Mussolini, the Grand Council of the Fascist party is to present a panel of three names to the King, from which he will choose the new dictator.[2] Of course this rather artless device does not guarantee a peaceful transfer of power. At the last moment the King might balk, preferring to regain his former position in the state; or, if he played the part assigned him, it is still more likely that the two rejected nominees might join forces against their successful rival. In any event underground plotters, aided by returning émigrés, would be sure to seize so favorable an opportunity for counter revolution.

It is easy to understand the reluctance of dictators to provide for a definite succession notwithstanding that neglect to do so may bequeath a civil war to their fellow countrymen. Mussolini's conduct has repeatedly exhibited the motives that, although unavowed, nevertheless operate in such cases. Like all other rulers of his type he is jealous and afraid of younger leaders of his own party. And with good reason, since any one of them possessing the peculiar abilities which are requisite for the job would not cherish the slightest scruple about seizing power for himself.[3] Dictators achieve dominance by the remorseless snuffing out of rivals; thereafter, in spite of the common belief that they are strong men, they spend their lives in constant terror of the same fate. In the

[1] Emil Ludwig, *Talks with Mussolini*, Boston, 1933, p. 133.

[2] According to rumor the panel has been drawn up already, Mussolini being present, of course, when this was done. Naturally there is much speculation in Italy as to the names appearing on it. One is said to be that of Count Ciano, Sr., whose son is the husband of the dictator's favorite child, Edda. Thus dynastic dreams on the part of the *Duce* are coyly intimated. See "Fortune," vol. x, no. 1, p. 51 (July 1934).

[3] As in the cases of deBono, Balbo, Grandi, Bianchi, Giunta, Farinacci, Turati, Giuriati and numerous lesser lights. See "The Change of the Guard," in *Fortune*, p. 126, *ibid.*

case of Hitler, who may be strong but who certainly is given to hysteria, the result was the remorseless butchery of his own party colleagues to the admitted number of seventy-seven on June 30, 1934. Under such circumstances it seems vain to hope that dictators will ever deal adequately with the problem of succession. On this important point their system is manifestly weaker than that of well-established monarchies or democracies in which kings of widely differing characters or premiers and presidents of opposing political parties succeed each other without the slightest disturbance.

The second major difference between absolute monarchs of the Eighteenth and earlier centuries on the one hand and contemporary dictators on the other is that the former ruled by right divine whereas several of the latter have always been more or less at odds with ecclesiastical authority. Up to the time of his assassination, July 25, 1934, Dollfuss, a sincerely pious Roman Catholic, was the principal exception to the latter part of this rule. Soviet Russia, indeed, went farther than any of the other dictatorships; it attacked not only the established church but also religion itself. By persecution and propaganda the Bolsheviks have destroyed belief among large masses of the people; they have even succeeded in dressing up their communist dogma with red ceremonials so that it serves as a materialistic faith. Curiously enough Mustafa Kemal has been almost equally drastic in his dealings with Mohammedanism in Turkey.

In Italy on the other hand Mussolini quietly abandoned the blatant atheism of his salad days and on June 11, 1929, entered into an alliance with the Church.[1] Subsequently, however, the *Duce* and the Pope have had numerous heated controversies in the course of one of which the Holy Father did not hesitate to refer to his antagonist as "the devil in person."[2] Hitler, himself nominally a Roman Catholic, followed Mussolini's example by making a concordat with the

[1] For English translations of the texts of the documents signed on that date, see *Italy Today*, No. 5 (May, 1929).

[2] Cf. George Seldes, *The Vatican: Yesterday—Today—Tomorrow*, New York, 1933, p. 385.

Vatican. However its observance by Nazi authorities has been so unsatisfactory that tension increases day by day. Neither has the situation been improved by the *Führer's* habit of sending priests to concentration camps, nor by his inclusion of leaders of the Catholic Action group among other victims of the massacre of June 30, 1934.

It is from the side of the German Protestants, however, that Hitler has met the stiffest resistance. They objected strenuously to reorganization under Nazi control; neither are they favorably impressed by the religious vagaries fostered by certain leaders of that party. Many of the latter advocate substitution outright of the warlike Wotan for the Christian deity; others adhere to a Germanic-Nordic. faith which, of course, would exclude all non-Aryans utterly; still others, who call themselves German-Christians, wish to abolish the Old Testament *in toto* and to revise the New Testament by deleting the "superstitious portions" and inserting a "heroic, fighting Christ." However the most extreme development of Nazi novelties in the religious field occurred late in 1934, when Hess, Ley, Rosenberg, von Schirach and other party leaders organized a politico-religious corporation. The avowed purpose of this curious combination is to set up Adolf Hitler and the Third Reich as divinities who are to receive the adoration of the German people.

In general, therefore, the aim of the more important dictators of the present day has been either to abolish religion or to bring the church under their domination, or at least, as in Italy, to secure its cooperation. Not that dictators are necessarily irreligious or anti-religious at heart; however, having set up a totalitarian state, they do not dare tolerate any organization with wide influence over the masses which might foment opposition to their absolute power. The same principle applies, as will be shown later, to political parties, to trade unions and cultural groups of every description which do not surrender unconditionally to the new regime.

Dictators are not alone, however, in advocacy of the cult of absolutism. Various churches, particularly the Roman

Catholic church, are also devoted to it, which means good hunting when the two powers, spiritual and temporal, are agreed; for example, both Mussolini and the Pope are willing enough to cooperate in making life miserable for liberals, Socialists, Communists and Free Masons. But it also means conflict, the particularly envenomed sort of conflict that can be waged only between absolutes, when the two do not agree. Nowhere is this more evident than in the innumerable struggles that have broken out over youth organizations. Modern dictators, as we have seen, aim to perpetuate the systems they have established; hence their constant efforts to train the whole of the on-coming generation in accordance with their point of view. Regarding itself as eternal the church also has never lacked solicitude for the proper upbringing of youth. Conflict between the two on this score is, therefore, irrepressible so long as both survive.

Although contemporary dictatorships thus differ sharply from the absolute monarchies of earlier centuries, first, in their attitude toward succession, and second, in their relation to the church, nevertheless the resemblances between the two far outweigh the differences. It is primarily the absolutism aimed at by both which makes them brothers under the skin. One is quite justified, therefore, in referring to our present-day dictatorships as reactionary. Politically they are throw-backs to the period preceding the French Revolution. At this point, however, a distinction must be drawn between dictatorships of the left which build up from labor and peasantry, and dictatorships of the right which build down from the higher classes of society—large capitalists, landowners, army officers, and the like. Soviet Russia is the only example of the former type; nevertheless in the political sense it is, like Fascist dictatorships of the right, also reactionary. Nor can it be denied that the present Communist regime is quite as absolute (and a great deal more energetic in action) than the former Czarist regime. In economic policies, however, the Bolsheviks have developed a radicalism of the most fundamental character; thus the U. S. S. R. combines political

reaction with extreme economic radicalism. Fascist dictatorships on the other hand, have devoted themselves strenuously in the main to the maintenance of the status quo—indeed we are constantly assured that they alone can preserve private property and the capitalist system against Communist attacks; hence they represent a combination of political reaction with economic conservatism. Perhaps the latter term is too mild; certainly if one takes into account what Mussolini and Hitler have done to the trade-union movements in Italy and Germany it is not too much to label them economic reactionaries rather than economic conservatives.

Since the resemblances between absolute monarchies and contemporary dictatorships are so great why should not attempts be made to transform the latter into the former? As a matter of fact that is exactly what Cromwell and the two Napoleons did try to do, all three of them without success. Such attempts are less likely at the present time; the prestige of monarchy is not great enough to make it worth while. In the case of Soviet Russia it is manifestly incompatible with communist ideology. As a rule even Fascist dictators, prior to their achievement of power, have sought the support, among other disgruntled elements, of Social Democrats. Since the latter are as much democrats as they are socialists, any effort on the part of a *Duce* or *Führer* to assume the crown might result in embittered opposition. Moreover the sort of government our contemporary dictators have set up requires a succession of strong men if it is to prove permanent. Since sons of dictators are not likely to be chips of the old block hereditary succession is too dangerous to contemplate seriously.

The policy of Mussolini in retaining the Italian monarchy together with various other institutions which antedate his march on Rome, suggests the possibility of restorations elsewhere. It is noteworthy, however, that the royal power of the House of Savoy, never great under the *Statuto*, is permitted to survive only in mummified form. As Fascist countries, Austria or Germany might seek to extricate them-

selves from grave difficulties by recalling some scion of their former ruling houses. Short of impending ruin however, no dictator is likely to take such a step. Even though the monarchs thus restored were permitted only to reign, not to govern, they would, if possessed of any real ability, become potential sources of resistance to the dictator. In case the latter were to commit some grievous error, opposition forces would mobilize at once around the king, urging him either to appoint another dictator or, better still, to assume absolute power himself.

Definitions of dictatorship usually presuppose a condition of emergency prior to its establishment. However it must be remembered that advocates of this type of government are notoriously inclined to magnify the perils which make it necessary for them to step in to save the state. Certainly it can not be maintained that every emergency, regardless of its extent or duration, justifies resort to dictatorship. Desperate remedies are for desperate diseases only. Moreover an emergency may be of the most serious character and yet be met adequately in other ways. Thus the American revolutionary war, while menacing enough to the patriots, was fought by them to a successful conclusion under a conspicuously weak and diffuse confederate government. Possibly a dictatorship—although such a thing is scarcely thinkable, given the time and the people—might have brought the struggle against the mother country to a victorious end much earlier. In that case, however, our ancestors would have found themselves compelled to undertake a second revolution later on in order to get rid of the dictator, instead of settling down peacefully as they did in due time under a strong federal constitution.

Various other periods of emergency have been met by free peoples without resort to dictatorship, e.g., the Sonderbund war of 1847 in Switzerland, the Civil War in the United States, the World War so far as France, England and the United States were concerned. In all such cases it is undeniable that the executive arm of the governments concerned

received a large temporary accession of power; afterwards, however, the normal balance between various constitutional organs, including particularly the legislative which receives power directly from the people, was restored.

It is not the case, therefore, that all emergencies encountered by democratic states result in the establishment of dictatorships. Hence one must inquire why certain emergencies have that effect while others do not. Apart from the extent, duration and suffering entailed by an emergency, the most important single factor seems to be the political training in self government of the people concerned. Neither the Russians, the Italians, nor the Germans had enjoyed any long training of this sort; indeed they turned to absolutism precisely in the order that such training was lacking. First to take that step were the Russians, and it may be pleaded in extenuation that they had been habituated to Czarist autocracy for more than four hundred years. Second in order of time were the Italians who had enjoyed a very limited measure of popular rule under the Statuto of 1848. It was not until 1912 that they received the grant of manhood suffrage. Meanwhile their parties were numerous and weak, being the personal following of strong leaders rather than well organized groups devoted to certain principles and policies. Third in acceptance of dictatorship were the Germans who had been given manhood suffrage as early as 1867. Even under the Hohenzollern emperors from 1871 to 1918, they developed a strong party life which was extended and greatly increased in power during the existence of the Weimar Republic from 1919 to 1933. It is factors such as these which explain the long resistance of the Germans to the seductions of Hitler; further they explain in large part the manifest shakiness of his regime although it has been in power less than two and a half years.

So far as the extent, duration and suffering entailed by an emergency preceding the establishment of dictatorship are concerned, a maximum case may also be made out for the Russians. Considering the terrible losses inflicted upon them

during the World War—to say nothing of the centuries-
old tyranny, corruption and inefficiency of the Czarist
regime—the only wonder is that the Romanoffs were not
overthrown at a much earlier date.   Italy's case is far less
convincing; it did not enter the war until 1915; it came out on
the winning side and received a large part of the spoils for
which it had bargained.   Other nations took the losses and
hardships suffered between 1914 and 1918 with a degree of
sang froid; long before the rise of Mussolini's star, however,
the statesmen of the peninsula whipped their fellow country-
men into a state of acute indignation over their alleged un-
requited sacrifices.   As for the economic wounds inflicted
upon Italy during the World War it is quite clear that they
had begun to heal before the March on Rome.[1]   Germany's
plight after 1918 was far worse than that of Italy; it had lost
the war after heroic efforts, gone through a revolution, been
deprived of territory and subjected to heavy reparations;
later it was made to suffer all the consequences of unlimited
inflation.   Nevertheless it took Hitler fifteen years to con-
vince something approaching a majority of the people that
his famous stab-in-the-back theory was correct and that Nazi
dictatorship alone would restore their power and prestige.

In considering the emergency argument as raised by
advocates of dictatorship one must not forget that to the
argument they always add their most strenuous efforts to
make actual conditions worse.   Bad as things were in the
Russia of 1917, and to a much less extent in the Italy of 1922
and the Germany of 1933, still it is evident that the revolu-
tionary elements in all three countries deliberately endeavored
to cripple the existing government, to foment violence and
disorder, and thus to increase the misery of the people.
Their theory was "anything to win," relieved only by the
pious hope that the particular brand of salvation they
preached—Communist or Fascist—would atone for all lives
lost and for all material damages.   A people possessing

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[1] Mussolini himself admitted this in the *Popolo d'Italia* of Nov. 10, 1920.   Cf.
G. Salvemini, *The Fascist Dictatorship in Italy*, New York, 1927, p. 33.

political common sense and some experience of self-govern-
ment would have seen through tactics of such crudity.
Nevertheless they were completely successful in the three
countries under consideration.

With absolute power finally in his own hands the new
dictator must decide promptly what is to be done with the
remnants of the former government. For some time, that
is until he can train a sufficient number of his followers, he
must depend for technical services upon the rank and file of
the old bureaucracy, meanwhile officering it with his more
trusted lieutenants. As to policy-determining organs of the
former government, action has taken various forms. In
Russia the Communists made virtually a clean sweep of
the ancient Czarist structure, replacing it with their own
completely new Soviet system. So far Mussolini has retained
Crown, Senate and Chamber of Deputies; recently however,
he referred to the last named as "anachronistic" and an-
nounced his intention to substitute for it one of his novel
creations, the National Council of the Corporations. In
addition he has set up the Grand Council of the Fascist party
and, largely on paper, his so-called Corporative State; all the
foregoing structures, old and new alike, being thoroughly
under the *Duce's* control. After making it an almost one
hundred per cent Nazi body Hitler continued the Reichstag;
the presidency was also retained until the death of Hinden-
burg whereupon the dictator annexed the powers but not the
title of that office to himself as *Führer* and Reich Chancellor.[1]
In short it is the general rule of dictatorship either to abolish
the organs of the old government, or, if some of them be
deemed worthy of retention, to provide for their complete
subjection to the power of the new chief of state.

As monopolists of power to the most extreme degree
possible, dictators naturally exalt the executive over all other
organs of government. Legislatures become sounding boards
for their orations and rubber stamps for their decrees. The

[1] Cabinet decree of August 1, 1934, sanctioned by the plebiscite held on the 19th
of the same month.

judiciary may be permitted to carry on its former processes in ordinary civil and criminal cases but in two particulars it must be subservient to the wishes of the dictator; first, it must punish the enemies of his regime with Draconic severity; second, it must find loopholes of escape for criminals who have served his ends. If the established courts do not meet these requirements special tribunals are created which can be depended upon to function satisfactorily. No more illuminating utterance on the attitude of dictators toward the judicial power has ever been made than Hitler's stammering statement following the butchery of his own followers, June 30, 1934: "In this hour I was responsible for the fate of the German Nation, therefore the supreme court of the German people during these twenty-four hours consisted of myself." [1]

In the light of the above facts dictatorships may now be compared with the parliamentary and the presidential types of government. Under the parliamentary type the legislative dominates the executive theoretically at least; in any event an adverse parliamentary vote on any important issue compels a change of ministry. Under the presidential type the executive enjoys a fixed tenure and acts within the sphere of power assigned to it ordinarily without encroachment; each of the three great organs of government—legislative, executive and judicial—while subject to certain checks and balances, is supreme in its own field. Under both the parliamentary and presidential systems final power rests with the people acting through free elections. Dictatorship is clearly set apart from these two types of government. It exalts the executive above all else; the legislative may be sent home or abolished, or, if permitted to hold sessions, is made subject, together with the courts, to the executive. Finally, and most important of all, methods of popular control are adopted which can be depended upon to make the voice of the people the voice of the dictator so long as he remains in power.

[1] *New York Times*, July 14, 1934, p. 7.

Similarly absolute executive control of all local government organs is essential under dictatorship.[1]

Dictatorial governments suffer therefore from hypertrophy of the executive and concurrent atrophy of the legislative, the judiciary, and local administration generally. They justify this pathological condition positively by the alleged existence of an emergency and the need of a strong man to overcome it. Negatively they pick flaws in the more deliberate processes of legislation and judicial determination, pointing out the everlasting flow of parliamentary oratory in the one case, the libraries bursting with court reports in the other, and emphasizing particularly the evils of delay, evasion and compromise in both cases.

Unfortunately this somewhat hackneyed line of argument overlooks the grave dangers of executive absolutism. "The primary vice of dictatorship . . . is action without prior criticism of the proposals involved."[2] Not only is prior criticism in parliament suppressed; it must be remembered that opposition parties and the public press are subjected to the same treatment. Moreover so long as their power lasts, dictatorships habitually suppress criticism *after* as well as *before* action is taken. Thus "a long train of abuses and usurpations" both against individuals and social groups may take place without redress except by counter-revolution.

By far the greatest danger of "action without prior criticism" lies in the concentration of the power to declare war in the hands of the dictator. It is true that none of the democracies of the world has gone so far as to provide for a popular referendum on this momentous issue. Nevertheless in all of them the declaration of war requires a parliamentary vote, which in the nature of the case is preceded by a large volume of free discussion by party leaders, in the press, and among the masses of the people. None of these safeguards exists under dictatorship. Decision rests solely with the dictator after he has listened to such advice as is available from

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[1] For details as to Germany, Italy and Russia, see the author's *Deliver Us from Dictators!*, Philadelphia, 1935, ch. ii.

[2] H. J. Laski, *Democracy in Crisis*, Chapel Hill, N. C., 1933, p. 81.

his hand-picked camarilla of one-party chieftains.   The conse-
quence may well be, as in the case of Louis Napoleon, a Sedan
debacle.   Far worse, however, is the possibility that a second
world war, involving nations regardless of their forms of
government, may result from hostilities thus undertaken, in
the last analysis, upon the decision of one man.

As a rule, moreover, dictators foment a warlike spirit and
therefore run considerable risk, whenever foreign relations
become tense, of being caught up by it and hurled into danger-
ous adventures.   Military discipline naturally appeals to
them more strongly than to other rulers; gladly would they
extend the habit of unquestioning obedience to the civilian
masses of their peoples.   At all times it is vitally necessary to
keep the regular army on their side; in addition some of them
maintain private armies of their black-shirted or brown-
shirted followers.   Further, the youth organizations which
dictators foster with peculiar solicitude are semi-military in
character.   To inspire all these armed groups with the proper
martial spirit, and incidentally to impress upon civilian
citizens the threatening danger of foreign attack against
which they are taught that the dictator and his regime are
their only protection, more than a little saber-rattling is
necessary, also constant drum-and-trumpet oratory.   From
jingo speeches to ultimatums is a short step; neither is it easy
for a dictator to back down in the face of followers to whom
he has preached warlike virtues incessantly.

Various cautionary factors reduce the danger from this
source to some extent, however.   Intending to retain per-
sonal power as long as they live, also if possible to perpetuate
their newly established regimes after them, contemporary
dictators have reason to be wary of actual hostilities.   Long
established governments like the greater democracies of the
world may hope to survive military defeat.   On the other
hand nothing is more certain than that a dictator who loses a
war also loses his power.   Even if lucky enough to escape into
exile he is doomed to witness the downfall of the "imperish-
able" regime he established.

Other factors both personal and general are involved.
There are marked differences in the characters of dictators;
at any given time each of them faces a special combination
of circumstances. So far as Russia is concerned a peace
record of eighteen years standing, maintained recently in
spite of numerous provocations by Japan, is fair evidence that
Stalin and his immediate associates are too thoroughly en-
grossed with the "building of socialism" to desire any actual
test of the fighting strength of the Big Red Army. Mussolini
also has kept the peace since 1922. As age overtakes him he
seems somewhat less inclined to truculent utterances such as
were so frequent during his earlier years of power; neverthe-
less his recent attitude toward Ethiopia is far from reassuring.
Both Stalin and Mussolini preside, albeit with considerable
friction, over regimes which, for the time being at least, seem
to be going concerns. History indicates that it is the dictator
facing internal disintegration who is most likely to resort to
war, no matter how desperate the outlook, in the hope of
concentrating power again in his own hands. It is precisely
this situation, which, coupled with his life-long advocacy of
violence, makes Hitler so great a menace to European peace
at the present time.

One of the most striking characteristics of contemporary
dictatorships is the one-party system which they have es-
tablished. It distinguishes them sharply from earlier govern-
ments of the same type which were based primarily upon the
army. Of course all former dictators, Cromwell and the
first Napoleon for example, dealt harshly enough with their
political adversaries. However they were military men *par
excellence;* they gained power by military *coups d'état* and
sustained themselves therein at bottom by the same means.
In a sense they disproved the old adage that "you can do
anything with bayonets except sit on them." Moreover
political parties as at present developed were unknown in
their times. The contemporary dictator who prefers a ballot-
box—that is a ballot-box which he can manipulate at will—to
a sword, may thus seem to represent a certain advance over

his epauleted predecessors. As James Bryce points out,
however, in South America, where a similar development has
taken place, the principal result was the substitution of fraud
for force.[1]

In several important respects the two-party or multi-
party systems which have long existed in democracies, differ
sharply from the one-party systems which have been set up
recently in Russia, Italy, Germany and other contemporary
dictatorships. The primary function of the former is to make
nominations to public office. Afterward campaigns are
waged in support of candidates. Between elections each
party brings pressure to bear upon the government in support
of its principles and policies. Granted that there is much
corruption, chicanery, misleading propaganda—at times even
some violence—in these processes, nevertheless they are
carried on in the open, as a rule peacefully, and they do
ventilate in thorough-going fashion the merits of opposing
measures and leaders. In order to win elections appeal must
be made to the whole or at least to a large body of voters.
Under democratic conditions, therefore, parties cannot afford
to be exclusive.

On the other hand the one-party system which exists
under a dictatorship is concerned with nominations and the
carrying of elections to a negligible extent only. The former
are taken care of by the high command; as to the latter victory
is certain since there is no opposition. Stress is laid, of course,
on getting out all the voters and on winning as high a per-
centage of the total as is possible—or credible. To be sure
the one-party workers make themselves useful in these ways,
resorting not only to propaganda but also to violence and
terrorism on a scale undreamed of even in the most boss-
ridden wards of American cities. Never are they employed in
campaigns of education; the last thing that any dictator
desires is an electorate which is alert and well informed on
public questions.

Between elections and plebiscites, moreover, the functions

[1] *Modern Democracies*, New York, 1927, vol. i, p. 207.

of members of the one-party system in a dictatorship are quite unlike those performed by members of the two-party or multi-party systems in democracies. Uniformed at least as to shirts—brown, black or what not—they take part in incessant parades and demonstrations, forming a background and to some extent a body-guard for the dictator. The thugs in their ranks are kept busy committing murder and mayhem on opponents of the regime, incidentally settling many private grudges at the same time. No dictatorship can survive without constant and universal spying; party members and even auxiliaries from the youth organizations are employed to aid the secret police in this unsavory work.

For these manifold and essential services rewards must be provided. The result has been an application of the spoils system on a scale hitherto unknown in the administrative service of European countries. In addition to this official patronage new jobs are created for the faithful in corporations and syndicates; pressure is also brought to bear on private employers to provide places for deserving black or brown shirts.

One characteristic activity of party members in a democracy—the effort to influence government in accordance with party principles—is severely restricted under dictatorship. In his ascent to power the dictator is obliged to promise everything; hence his following is motley and discordant. Once arrived at his goal, however, definite decisions have to be made and factional discontent is certain to be the result. Hitler in particular illustrates this principle; between 1918 and 1933 he appealed both to peasants and to large land holders; both to labor and to the great industrialists; he was both anti-Marxian and strongly national-Socialist. Since his accession to power he has broken with his left-wing followers, thus earning the embittered, even if concealed, hostility of many who worked and fought for him in the sincere conviction that his heart beat only for the common people. Naturally also many careerists attach themselves to a dictator on his way up. When his success is assured even members of

opposing parties make haste to join the one-party ranks either for protection, or to bore from within, or merely to share in the loaves and fishes.

With such self-seeking and mutually antagonistic elements to contend with among their own followers it is not to be wondered at that dictators feel themselves compelled to resort constantly to *chistkas*, cleansings, limitations of membership, banishment or imprisonment of factional leaders, even to mass murder as in the Hitler purge of June 30, 1934, or to mass executions as in Soviet Russia following the assassination of Kirov, December 1, 1934. Parties in democratic countries, as we have just noted, cannot afford to be exclusive; under dictatorship they must be kept relatively small, otherwise discipline vanishes. It is a curious fact that the membership of the one-party systems in Russia, Italy and Germany is but little larger in proportion to population than the membership of political committees made up of active partisan workers in the two old parties in the United States. It is no doubt true that the Communist party in Russia and the Fascist parties of Italy and Germany have many sympathizers in the general public outside, nevertheless these parties are made up exclusively of partisan workers and therefore resemble the machines of certain of our boss-ridden cities and states rather than parties in the proper sense of the word; for the latter must include not only such leaders and lieutenants as may be necessary but also a large rank and file membership.

In addition to disciplinary measures exerted over their one-party membership, dictatorships have been notoriously severe in stamping out opposition parties. The latter are liquidated, suppressed, dissolved, absorbed; their leaders are exiled, sent to Devil's Islands, thrown into concentration camps, deprived of property and citizenship, tortured, murdered. Similar severities are meted out to leaders of other opposition groups, racial, religious or economic. Violence becomes the order of the day; neither is it a temporary initial violence such as Machiavelli counseled, but rather sporadic

violence based on the famous maxim of the Kilkenny fair. Even when for the time being there is no visible opposition head to hit, unlimited terror and espionage must be loosed upon the population.   There is no freedom of discussion or of the press so far as the purposes of the dictator are concerned; on the other hand there is a never ending monotonous one-way propaganda by radio and by subservient papers in glorification of his person and in favor of his policies.   Schools from the kindergarten to the university are made the agents of political indoctrination; almost from the cradle onward the coming generation is goose-stepped into acquiescence by triple-ply youth organizations.   Education is debased; philosophy and the social sciences are compelled to bow to the powers that be, while emphasis is laid upon applied science, technology, the art of warfare, and, in Germany, upon the spurious anthropology which is called "racial science."   If dictatorships endure for any length of time the greatest loss they will inflict upon the peoples subject to them is the retrogression they will cause not only in the art of living but also in the arts of making a living due to the neglect of philosophy and the pure sciences.   For with the neglect of philosophy and the pure sciences technological progress is impossible.   And without technological progress civilization as we know it must come to a standstill.

Dictators never wax more eloquent than in the oratorical denunciation of democracy.   Nevertheless they have resorted to elections and plebiscites with a frequency approaching, and in some cases exceeding, that of the governments they overthrew.   In Russia, for example, millions of workers and peasants who never went to the polls before, have been voting constantly—always, of course, under the Communist one-party system—ever since the Bolshevik revolution of 1917. Mussolini who of all dictators has gone out of his way most frequently to express utter disdain for democracy, has held three general elections since the March on Rome in 1922. Hitler always spoke with withering contempt regarding the frequent elections which marked the last years of the Weimar

Republic; however within the nineteen months after he became Chancellor the German people were called to the polls more often than ever before in the same length of time.

Even more remarkable than the frequency of popular votes under dictatorship is their approximate unanimity. In the election of 1802, Napoleon Bonaparte's list of candidates received 99.766 per cent of the total number of ballots cast. Mussolini scored an even greater victory in his third election for the Chamber of Deputies held in 1934, when the hand-picked Fascist slate achieved a percentage of 99.882. In the plebiscite on foreign policy and the Reichstag election of November 12, 1933, Hitler rolled up percentages of 93.4 and 92.2 respectively. However in the plebiscite of August 19, 1934, ratifying his assumption of presidential powers, he won with slightly less than 90 per cent of the total number of ballots cast—a result which, although hailed by his supporters with frenzied jubilation, is so far below the best standards of dictatorship as to indicate danger ahead.

A certain suspicion must always attach to majorities so nearly approaching unanimity, especially when the whole election machinery, including the counting of ballots, is under the control of a single party. In Russia particularly, sentiment among the peasants who make up four-fifths of the population being what it is, one may well doubt even today that the Communists could carry the country in a free election. Similarly in other dictatorships there are masses of malcontents, members of former parties that have been suppressed or of groups that have been dispossessed and persecuted, who would vote against the existing regime if they dared. In the last analysis, therefore, the majorities achieved—so far as they are truthfully reported—must be accounted for largely by the violence, terror, and unlimited one-way propaganda so freely employed under dictatorship.

Why do dictators who profess to abhor democracy nevertheless resort frequently to such democratic devices as elections and plebiscites? Frankly counter to their utterances as the practice is, still it may be made to serve various

deceptive ends which they have in view. Unthinking ele-
ments of the population are flattered by the belief that they
have been called into consultation on political issues of great
importance. Why not permit them to indulge this illusion,
especially since elections and plebiscites can always be manip-
ulated to show apparently overwhelming popular support of
the regime? Further, no matter how misleading the victories
thus gained, they can be interpreted brazenly both at home
and to the outside world as evidences of the boundless admira-
tion and support of the people for the dictator. To be sure
these interpretations are heavily discounted abroad, but
domestic sceptics must remain silent. There is, indeed, a
possibility that certain popular tendencies revealed even by
strictly controlled elections or plebiscites may be of value
in determining the policy of the dictator. On the other hand
he is likely to be misled by them into a false assumption of his
own strength and security. Louis Napoleon, for example,
thus deceived himself immediately before his downfall in
1870. Finally the holding of elections under a dictatorship,
no matter how completely they are thimble-rigged, affords
some basis for the argument that, after all, it is fundamentally
democratic.

Government of this type is also asserted to be fundamen-
tally democratic on the ground that the dictator, being a
man of genius, at all times presciently perceives and im-
mediately realizes the will of the people. It is, however, im-
possible to believe that the above characterization applies to
all absolutist leaders, past and present. Cromwell and
Napoleon I were presumably men of genius, nevertheless
their regimes proved to be short-lived. And contemporary
dictatorships suffer from such severe internal stresses and are
driven so frequently to the use of violence, terror and espion-
age that their *Duces* and *Führers* seem to be anything but
infallible interpreters of the popular will. In any event the
people which permits one man to speak and act for it without
effective control is certain to lose any capacity it may possess
for democratic self-government.

Contrary to the above view which would make dictators merely mouthpieces and executors of the popular will, there is abundant evidence to show that dictators do dictate—within limits of course. Sometimes, indeed, they may represent a majority sentiment although there is no means of proving that fact; more often, however, they represent the views of certain groups to which they owe their elevation to, and maintenance in, power. Thus the effective support of Stalin comes largely from the industrial workers; the peasants have been at best the step-children of the Bolshevist regime. It would be most enlightening to have access to the ledgers of the industrialists, large landowners, bankers and war profiteers who financed Mussolini's March on Rome in 1922. Hitler's indebtedness to somewhat similar elements, particularly to the Thyssen steel, munitions and banking interests, is also beyond question. Undoubtedly it was at their command that the *Führer* later turned his back on all the fervent pledges of national socialism which had enabled him to acquire a mass following.

In addition to groups of the foregoing character dictators must always consult the interests of the army, hence their strongly militarist proclivities. Hordes of camp followers, one-party leaders, black-shirts, brown-shirts, workers in the youth organizations—must be kept placated by favors or, if necessary, rewarded by jobs. Of course political spoils are not unknown in democracies, but they must be more widely distributed and more frequently redistributed than in dictatorships. In democracies, moreover, civil service systems are better able to resist executive attack.

Of course no dictator rules purely in accord with his arbitrary likes and dislikes. He must consolidate the support of a sufficient number of important groups if his own power is to persist. Presumably he approves the ends which these groups have in mind; to that extent he is pursuing his own purposes when he favors their purposes. Particularly does this seem to be true of Russia where the favored groups were predetermined by Marxist theory. In Italy and Germany

the combinations supporting Fascism are far too motley to be explained on any ground except political opportunism; certainly Mussolini did not change his inner religious convictions when he made his famous alliance with the Pope.

One thing at least is certain, namely that the dictator must throw favors to the limited number of groups supporting his regime. So far as these consist merely of the spoils of office no great difficulty is to be apprehended, although the public service may suffer considerably. In dispensing economic perquisites, however, the dictator cannot avoid antagonizing large classes of the population. Regardless of his earlier campaign utterances Hitler, for example, decides to favor Thyssen, the Junkers and owners of large department stores; he must therefore be prepared to suppress the discontent of workers, peasants and small shopkeepers. In short dictators rule by favor and terror, favor for a set of special groups which support them, their white-list so to speak; and terror, backed if necessary by violence and supported by far-flung espionage, for all other groups which, at the least suspicion of opposition, are relentlessly blacklisted.

At this point the difference between democracies and dictatorships is sharply defined. The latter play favorites and practice repression; the former must endeavor to conciliate all groups since they grant universal suffrage, free elections, a free press, and the right to organize in parties and other associations. Conceded that some degree of favoritism exists in democracies—to capitalist interests, machine politicians, propagandist groups and the like; nevertheless it cannot ride roughshod over less privileged groups. Finally, once having made a bargain with fate, the dictatorship must continue in association with its own specially favored groups to the end of the chapter. The violence and terror which it employs against opposition elements precludes alliance with them. Hence dictatorship seldom approximates the general will; nearly always it diverges sharply therefrom in efforts to coddle its own favorites, hence also an accumulation of errors with their resultant hatreds, until at last repression fails and the inevitable breakdown occurs.

The principal counts in the political indictment against dictatorships may now be formulated as follows:

They intend to retain power permanently, regardless of changes of conditions or of the popular will. Hence they deserve to be called despotisms.

They come into power by means of revolution at times of crisis—or of alleged crisis—which the party supporting them aggravates by every means at its disposal.

They fail to provide for a definite line of succession, and are therefore exposed to a second revolution at the death of the dictator—or even earlier if his government proves insupportable.

In pursuit of the totalitarian ideal dictatorships attempt to destroy or subjugate religion and the church.

Whether radical or reactionary in their economic ends, all dictatorships are reactionary in political organization and policies.

They destroy or subjugate existing state structures regardless of the value of the functions which these structures perform; particularly do they attack legislative and judicial organs and the local government bodies in order that executive power in the hands of the dictator may operate with the least possible restraint.

As a result swift and sweeping executive action may be taken, but such action is likely to be unwise and destructive to the last degree.

Particularly is this true of the unrestrained power to declare war vested in the dictator alone; moreover through bellicose propaganda addressed to the army, the people and the semi-military youth organizations, dictators constantly foster the war spirit.

Dictatorships establish a one-party system, which in reality is a boss-ridden, spoils-seeking political machine. All other parties are suppressed; their leaders are executed, exiled or thrown into concentration camps.

The subservient members of the dictator's one-party system have little to do in the way of carrying elections;

their chief occupation is to march in parades, to man-handle and murder disarmed political opponents, to act as spies upon the large disaffected elements of the population.

Freedom of speech, of the press and of the radio are sup-pressed; all are used for incessant, monotonous one-way propaganda in favor of the dictator and his policies.

Schools are used to indoctrinate the young to obedience; academic freedom is destroyed; science and research languish as a result; in the end technological advance must cease under dictatorship.

Violence is ruthlessly resorted to whenever necessary; terrorism and propaganda are unceasingly employed by dictatorships.

Elections and plebiscites held under dictatorships are openly manipulated by the same means and are manifestly fraudulent.

Dictatorships consult the wishes not of all groups of the population but of certain favored groups only—labor, the Communist party, the Red Army, the GPU and to a less extent the peasantry in Russia; big business, big landlordism, the Fascist party and the army in Italy and Germany.

Other classes are oppressed economically, and deprived of political rights and of civil liberties.

In consequence of these policies common to dictatorships the least relaxation of terror and spying may lead to civil war.

Contemplation of the above catalogue of political errors is enough to show that in number and seriousness they far exceed anything that may be charged against the democratic governments of the world. In short dictator-ships suffer from much the same combination of patho-logical conditions which Aristotle noted in the case of the ancient Greek tyrannies, and like the latter they will probably prove to be extremely short-lived state forms.

As to the final decision between democracies and dictatorships one must fall back upon Hegel's "*die Weltgeschichte ist das Weltgericht.*"   Obviously the former suffer from many evils; to survive the present period of widespread distress they must develop energetic action and an intelligent program. Great as are the difficulties confronting the democracies of the world it may be said in their favor that they have come through earlier economic crises successfully; moreover several have waged war on a large scale without fundamental alterations in their constitutions.   On the other hand none of the contemporary dictatorships of Europe has met the latter test. Nor can any of them engage in warfare without the likelihood of being crippled by internal disaffection and sabotage.   It is true of course that these dictatorships emerged during a period of considerable material hardship.   Extravagant claims are made by propagandists regarding their success in dealing with economic problems, particularly unemployment; nevertheless living standards have declined in Italy and Germany and are still extremely low in Russia.   In spite of all their present difficulties the people of the United States, England or France have scant reason to envy any population living under dictatorship.   It is not the purpose of the present discussion to consider in detail the economics of dictatorship; nevertheless there is little probability that any peaceful and progressive solution of the problems in that field can be worked out by a one-man government supported by a one-party system based on restricted class or racial groups and relying in the last analysis upon violence, terror, spying and propaganda.

Even if dictatorships should succeed in establishing higher living standards than democracies, they would still have to face the heaviest counts in the indictment against them—reaction in politics, liquidation of the opposition, fostering of the military spirit, destruction of liberty and tolerance, the maintenance of a system in which "basic decisions are frankly imposed by power groups and violence may subordinate technical intelligence in social guidance." [1]

[1] *Recent Social Trends*, New York, 1933, vol. i, p. lxxiv.

"All things considered, however, violence is not the greatest of the evils entailed by dictatorship. That can be borne until, grown intolerable, revolt ensues. At bottom the worst offence of dictatorship is its vulgarity. Strip away the romanticized versions of itself concocted to gull the outside world, there remains only the lowest and basest concept of humanity. The dictator believes—his every word and action reveal it—that masses of men may be driven by force, cajoled by one-sided propaganda, seduced by purely material rewards. He believes, moreover, that such methods of social control will succeed permanently. In short he gambles that courage, intelligence and unselfishness are extinct in the human race. If so, it would richly deserve dictatorship as a punishment for its sins. That it is not so is best proven by the fate of dictatorships in the past; it is likely to be proven anew in the not distant future by the fate which, despite their present parade of power, threatens the equally obnoxious dictatorships of the present." [1]

[1] *Deliver Us from Dictators!*, Philadelphia, 1935, p. 241.

PROBLEMS PRESENTED BY A STUDY OF FIREBALLS RECENTLY OBSERVED IN AMERICA

CHARLES P. OLIVIER

DURING the past few years reports on over 1,000 fireballs have been received by the American Meteor Society. Of these, probably 80 per cent had only one observation, the other 20 per cent having from two to an extreme case of nearly four hundred observations—this last being the great Illinois fireball of 1929, July 25. Except on shower nights, fireballs come totally unexpectedly and they are in general seen only by persons with little astronomical training; consequently only for a small number can any really useful results be calculated. However, in some cases we are fortunate, and enough good data are available for the calculation of heights, orbits, train drifts, and other quantities. Altogether data from 35 fireballs, most of them very brilliant objects comparable to the Moon at various phases, have been worked up in recent years by me and my assistants. This paper attempts briefly to present some of the problems encountered and conclusions reached.

First it is well to state what results of value may be expected. Meteoric bodies, whether they are fireballs, meteorites, or merely so-called shooting stars, all come from outside our Earth and give us the one direct means of studying masses not of terrestrial origin. It is true that only the meteorite can be subjected to chemical analysis and mineralogical study, but by means of the spectroscope and by other methods something also can be found out about the other meteoric bodies. It is only with fireballs that we are directly concerned here.

When the observations on a fireball, itself a bright object

and perhaps having a long-enduring train, are both numerous and good, we may hope to determine directly the following data: the heights of beginning and end points, the length of the path and its shape in our atmosphere, the velocity, the radiant point (or point in space) from which the object came, the upper and lower limit at which the train remained visible, the direction and velocity of drift of the train, and the orbit of the body in space.   If variable velocity can be proved and evaluated in the path within our atmosphere, information as to densities at great heights may be derived.   If a spectrogram is available, the constitution of the body may be determined. And finally, if the body actually reached the ground, its fragments can be studied to determine composition and structure.

It will be noted that, strictly speaking. the information we obtain, with the exception of the orbit in space, is of more direct bearing upon the physics of the upper atmosphere than upon astronomy proper.   Specifically, we are furnished with means for estimating relative atmospheric densities which would cause observed retardations; and what is of greater importance, the train-drifts give us our main information upon wind directions and velocities at really great heights.

With this brief outline of the subject, a few general results will be indicated, and one case, which is typical and the most interesting, will be discussed in detail.   For 33 fireballs now ready for discussion (omitting the two Leonids which were considered in a paper presented here in 1933), the average height of appearance was 140 km. and of disappearance 36 km.   The extremes of each are 241 km. and 0 km., but neither extreme case is very certain.   If the two Leonids are included, we find 6 cases in which the train lasted from 3 minutes to 90 or more.   Of these, 2 or 3 were certainly partly smoke trains; the others were trains that could not have been touched by the Sun's rays.   Velocity and direction of train drift could be calculated for 4 cases, the three most reliable velocities being between 128 and 236 km. per hour.   Sound phenomena, sometimes of extreme intensity, were reported
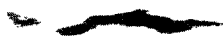
Photographs of the fireball's train showing drift to the east relative to lower atmospheric clouds. By C. R. West, Timpas, Colorado. Lens 3^{1}_{2} inch focus.

Middle of first picture approximately 10 degrees east of S. E. Train about 10 degrees above horizon. Total length of train about 40 degrees.

for 9 out of the 35. Eleven had their end or bursting point below 20 km., and hence probably dropped meteorites upon the surface of the Earth. Several of these, however, were over water, so that there was no chance for recovery. Only for the fireball about to be discussed at length are fragments known to have been found. There is no doubt that a few of these 35 objects, at least when they burst, illuminated the vicinity with a light many times brighter than the full Moon.

Of course these extremely brilliant ones are most exceptional. Out of 10 orbits calculated, only 3 showed retrograde motion, and 2 of these were Leonids.   Orbits were calculated, however, only when the radiant was believed to be well determined.   A large number of fireballs still await computation; naturally the above figures would be somewhat altered by their inclusion.

We will now discuss in detail the great Oklahoma-Texas-New Mexico fireball of March 24, 1933, the study of which brought in most of the points already mentioned.

THE GREAT BOLIDE OF 1933, MARCH 24

Before sunrise on March 24, 1933, one of the most remarkable meteors of recent years passed across parts of Oklahoma and Texas and ended over New Mexico.   Thanks to the American Meteor Society's having able regional directors in Arizona and in Texas, namely J. D. Williams and O. E. Monnig, more than the usual amount of data was secured.   Another active member, A. R. Allen of Trinidad, Colorado (54^1), also made personal investigations along the western part of the path and kindly communicated his results. He further sent an excellent photograph of the train.   In addition, C. R. West of Timpas, Colorado (47), sent a set of eight equally fine photographs of the train, taken at intervals during the first half hour after the meteor passed.

However, there were drawbacks.   The object appeared at 6:05 A.M., C. S. T., when twilight was strong and stars invisible.   Also, although several A. M. S. members and others capable of plotting the path saw the train, most of them were awakened by the sound of the meteor and got to the windows too late to see the object itself.   Therefore most of the reports of the path were from people who were never before called on for anything similar, and while they vividly remembered the effects and violence of the sounds, the colors, and the fact that the train endured a long time, their memories for exact directions and angles were naturally not so good.   We

[1] These numbers in parentheses are reference numbers assigned to stations from which observations were made.

believe, however, that a satisfactory solution of the path itself
has been obtained; unfortunately the calculations of the
direction and velocity of train drift are not so conclusive.

The first step of the solution was the usual one of de-
termining the points under the two ends of the path by the
observed azimuth lines. Next the height of the end point was
determined, using only the altitudes by observers very near at
hand, and finally a series of heights was calculated for other
points along the path, using the better visually determined
altitudes. These altitude estimates were greatly reinforced
by measures upon the photographs. Finally a straight line
was drawn through weighted mean points in this series of
heights, which obviously gives the average slope of the path.
A close study, however, shows it to be possible that for the
first two thirds of the path the slope was about $4°$ steeper than
the average, and that the path flattened out somewhat for the
last third. In determining the radiant, nevertheless, it
appeared best to use the average slope and ignore the possi-
bility of change of slope.

In this way the following conclusions were reached:

Time: 1933, March 24, 6:05 A.M., C. S. T.
Began over: $\lambda = $ $97°09'$ $\varphi = 36°33'$
Ended over: $\lambda = 104\ 25$ $\varphi = 36\ 06$
Ground Point: $\lambda = 104\ 55$ $\varphi = 36\ 04$
Height at Beginning: 141.2 km.
Height at End: 16.6
Projected length of path: 656.5
Actual length of path: 670.3
Slope (average): $12°$
Azimuth of path (from): $265°.6$
Zenith correction (approximate): $2°$
Sidereal time at ground point: $258°03'$
Radiant: $\begin{cases} \alpha = 342°.2 \\ \delta = +9°.4 \end{cases}$

The elements of the corresponding parabolic orbit are:

$$
\begin{aligned}
L &= 272°.4 \\
\Omega &= \quad 3.4 \\
i &= \quad 73.6 \\
\pi &= \quad 56.1 \\
\log q &= \quad 0.51
\end{aligned}
$$

The von Niessl-Hoffmeister Catalogue shows no fireball in the latter part of March which could come from this radiant. This fireball therefore belongs to no well-known stream.

Every effort was made to derive accurate directions and velocity of the train drift, but only partial success was attained. The results actually derived were based largely upon (I) visual observations and eight photographs by C. R. West at Timpas, Colorado (47); (II) visual observations (one made with a quadrant) and one photograph by C. R. Allen at Trinidad (54); (III) drawings and full description of position of train in sky by W. E. Baker at Boise City, Oklahoma (53); (IV) a fine series of six colored drawings by V. M. Martinez, five miles east of Wagon Mound, New Mexico (32); and (V) an excellent account, with discussion, by W. A. Schmidt, then on a train going west from Trinidad, Colorado (55). Parts of the meteor train were visible for fully an hour and a half.

Fortunately (32) was almost in the plane of the fireball's path. The six colored drawings show not only the various shapes taken by the train, but also the mountains on the horizon, and the last one also shows the rising Sun. The axis of the train appears vertical in the drawings and seems not to have shifted with respect to mountain peaks below. The final azimuth can be checked by the Sun. The train spread laterally to quite a distance at certain places, and also shortened vertically. It is impossible to determine the scale of the drawings, but they do prove that the axis drifted practically parallel to itself and in the plane of the fireball's path.

The drawings at (53), made from a point not far north of

the path and with three quarters of total path to eastward, show that the three brightest "clouds" in the train drifted slowly to a little south of east. From the diagram I infer a motion of $15°$ in 60 minutes, approximately (the direction of drift making an angle of $25°$ with the vertical), or about 280 km. per hour (in a direction $40° \pm$ S of E??).

Unfortunately the exact times of the photographs at (47) (five taken with a kodak $f = 3.5$ in., three with one $f = 7\frac{1}{4}$ in.) were not noted, though a record was made of the approximate time of the middle of each series. The accurate times are also missing for the photograph from (54). Also the only things to which angular motion can be referred in any of the photographs are lower, small clouds, which drifted in the same direction as the train but more slowly. Any measures of velocity referred to these are obviously too small, but they are the best approximations to a measured velocity that we can make. The observers stated that the clouds moved slowly. From West's letter (47), it is certain that twenty minutes was the maximum interval between first and last exposure with the smaller kodak, i.e., the time from 5:05 M. S. T. to 5:25, when he began with the larger kodak. Making allowances for delay at each end, we assume a total interval of fifteen minutes. The relative drift (drift of the train with respect to the clouds) was measured as $10°.8$ on the photographs, or practically $2'3°$ per minute. The velocity from this measure is then 273 km. per hour, by chance in agreement with that from Baker's observations. The probable error is unfortunately 30 to 40 per cent. The direction of drift cannot be more closely defined than in general toward the east.

Allen (54) states: "This cloud [the train] drifted rapidly east or away from our position at Trinidad. Our position at Trinidad is so much in line with the path of the meteor that the cloud seemed to be drifting away and downward. . . ." He measured, with a quadrant, the altitude of the top of the cloud-trail as $13° \pm 1°$, at 5:20 $\pm$; he states definitely that the picture was taken "30 minutes after meteor passed," i.e.,

5:35, but in a later letter he says that it was 4 minutes after his quadrant measure, *i.e.*, 5:24. Evidently memory cannot be trusted.

I am able to identify one of the condensations on Allen's photograph with one on West's second series; the latter unfortunately does not show the lower moisture-clouds or the horizon by which azimuths and altitudes might be computed. West's first series shows both. We further cannot be sure of the actual time of either photograph closer than that they were both taken between 5:24 and 5:35 M. S. T. Allen gives the azimuth of the east end of his train as 276° and the altitude as 8°. Assuming the exposures coincident at 5:30, I calculate that West's east end of the same condensation has an azimuth 275° and altitude 8°. All this proves that we are within a few degrees of the truth as to actual directions from both observers; but the error turns out to be several times the parallax, so we cannot compute the drift from these two positions. However, we do get an excellent check on the height of the eastern end of the brightest part of the train, which at 5:30 ± 5 m was 102 km.

Our most detailed description was sent in by Walter A. Schmidt (55), a scientist and a chemical engineer with the Western Precipitation Company, who was on a train just past Trinidad, and had an excellent view. He describes the head as dazzlingly blue-white and the path as "a straight line path essentially parallel to the horizontal tangent to the earth's surface . . . and traveled southwest." He watched the trail for over an hour, until the sun was up.

. . . "It appeared to be self luminous throughout its entire length for a brief period of time. Then this apparent luminosity localized itself to the zone where the greatest intensity of light, and probably heat, took place. This was at the place where I first saw the meteor in its flight. What it looked like ahead of that spot, I do not know, but my guess is that it was rapidly becoming brighter up to that point. I will call this point the center of the trail so as to be able to describe more simply. Ahead of this center, the trail looked brownish or yellowish. Beyond the center, it was bright white. It looked suspiciously like a dust streak ahead of the center

and a fume streak beyond the center. From the center to the end, the fume streak tapered down, indicating that the cluster had a considerable diameter at the start and ended up with the last fragments. The unexplainable phenomenon is that the center remained brilliantly self luminous for a long period of time. At first the entire fume streak beyond the center was luminous, but after a few minutes all but the center became dark, or at least relatively dim. The bright center had a length of about five to ten degrees. This center looked like hot luminous gas, but as the brightness lasted over a half hour, such an assumption seems unreasonable. It was apparent that this smoke trail was at a high elevation, so I tried to explain the light by assuming the sun's rays illuminated this part of the streak, but to accomplish this, the path of the meteor would have had to be such that this spot alone would have been carried out of the earth shadow, and this seems quite impossible, considering the apparent track. Furthermore this one central zone alone remained luminous for a full half hour. Then the morning dawn started.

"During this half hour before the break of dawn, a most peculiar phenomenon took place. The smoke streak, except for the very last thin extension, gradually contracted longitudinally. The contraction was not regular and may have been due to winds, but considering the great linear extension, the action is difficult to explain on the basis of wind currents. After a half hour, the streak of white fume had so shifted itself as to look like an extended cloud reaching westward from the brilliant luminous center. The entire phenomenon strongly suggested electrical action. One most interesting feature was that the brownish or yellowish trail ahead of the center played no part in this cloud-gathering effect. When the sun rose, the streak ahead of the center had disappeared, while the large cloud around the center and smaller patches to the end of the track were visible in the full sunlight, again suggesting a difference between the earlier and later portions of the smoke trail, as though these portions were dust and fume respectively.

"When the sun rose, the meteor smoke cloud was fully illuminated probably ten minutes before the lower lying clouds were touched by the sun's rays, showing that the meteor's path was far above the earth's surface."

Most reluctantly I am forced to leave the problem of the train drift relatively unsolved. All we can say is that it moved in general to the east, that it did not greatly change its height, that the train itself broke up or contracted into knots or condensations, that isolated knots certainly expanded north

and south also as they generally drifted eastward, and that the drift was of the order of 300 ± 100 km. per hour. We further know that the west (and fainter) end of the train, when it was first photographed, about five or ten minutes after the meteor passed, was only 25 ± km. high, that the western "knot" about 5:30 was 30 ± km. high, and that the brightest condensation far to the east was slightly over 100 km. high somewhat later. However, the western half faded relatively soon; the eastern half, *i.e.*, from 60 ± km. to 100 ± km., lasted over an hour.

According to a report published in *Popular Astronomy* for February, 1934, page 106, by H. H. Nininger, meteorites have been recovered. He also gives heights for the two ends (78 miles and 17 miles), the slope (8.5°), and azimuth of the body's path (257.5°). These differ somewhat from the values derived here. He has further published a photograph by C. M. Brown, taken at Mt. Dora, New Mexico, which shows the body coming almost head on, in a most distinct spiral. Professor Nininger has published a full description of this object, with the results of a personal investigation he has made along its course.[1]

Sound phenomena caused by this bolide were very noticeable at some places, violent at others. The following table gives data from many stations as to sound, color, and other notes of special interest. Plotting on the map those stations from which violent explosive sounds or at least sounds like heavy thunder were heard, we find that they extended at least 100 km. both north and south of the last 300 km. of the path. For most of its path the bolide seems to have been bluish-white, probably growing redder toward the end. Many observers in replying to our questionnaire evidently confused the colors shown by the train with the color of the object itself.

As for the velocity and type of motion of the fireball, at (51) it "was spinning furiously." The photograph taken by C. M. Brown (mentioned earlier) shows a most decided spiral. It was taken not far from head-on. From (16), Big Springs,

Station	Observer	Place	Sound Heard	Color
1	J. W. Richmond	Borger, Texas	4^m after,[1] big blast in W, windows rattled.	Pale blue
2	D. P. Bissell	Guymon, Okla.	$6^m \pm 1$ after, loud report, rumblings 5^m longer.	Blue-white
4	R. D. Norton	Amarillo, Tex.	$5^m \pm$, explosive sound, shook buildings.	Blue
5	L. Wirt	Canyon, Tex.	15^m, like distant thunder, earth tremor.	Light orange
6	D. L. Brown	Sudan, Tex.	Did not hear actual explosion.	Red
8	L. Ashby	Dalhart, Tex.	5^m-6^m, thunderous roar.	
9	Mrs. J. C. Cooper	Muleshoe, Tex.	No sound; size full Moon when exploded.	Red; then white
10	R. B. Read	Tucumcari, N. M.	No sound; ⅔ size Moon, did not explode.	Light orange
14	G. F. L. Bishop	Canyon, Tex.	Heard no sound.	Blue-green
19	J. W. Suhler	Campo, Colo.	5^m by clock, like distant thunder. Train lasted one hour.	Star
20	J. W. Baxter	Yuma, Ariz.	No sound, no explosion.	Blue
21	E. Y. Hill	Campo, Colo.	$3^m \pm$ after explosion.	Bright red
22	Mrs. M. M. Gitchell	Campo, Colo.	4^m-7^s after explosion.	Y-W-B-G
26	J. M. McCrackin	Clayton, N. M.	3^m after explosion; series of 16 explosions.	Blue-white
28	Cherry Moody	Grenville, N. M.	3^m after explosion, nearly size Moon.	V. light
29	Tobias Garcia	Levy, N. M.	1^m after explosion.	Red
30	Mrs. I. Zimmerman	Levy, N. M.	$4\frac{1}{2}^m$ after explosion.	Star
32	V. M. Martinez	Wagon Mound, N. M.	10^s after explosion; threw off 3 red fragments.	Fire
34	Father F. Edward	Guymon, Okla.	$4^m \pm 1$, house shook.	
35	M. B. Duke	Claude, Tex.	Broke twice, later sound like thunder, rattled windows.	
51	G. R. Calkins	Grenville, N. M.	$5^m \pm$, exploded twice, then rolling thunder.	
52	A. M. Reese	Dalhart, Tex.	3^m, terrific explosion, shook buildings.	
53	W. E. Baker	Boise City, Okla.	From 5^m to 6^m after flash, roll of thunder.	

[1] The observers were asked "Did you hear any sound? How long after seeing the meteor was it before you heard this sound? Did you hear an actual explosion? How long after seeing the explosion was it before you *heard* it?"

Nebr., H. F. Wagner says: "greenish ball of fire . . . moving rather slowly with a rapid spinning (anticlockwise) motion. . . ." From (17), Santa Fe, N. M., J. A. Rivera says: "Its center was reddish in color and seemed to be whirling, but I could not determine its direction." From (26): "Two lines of smoke on either side and parallel to each other. There were 16 pulls or waves, in the lines, each one arching out." From (27), Clovis, N. M., J. R. Sorrows writes: ". . . whirling over and over losing small chunks all along." From (47): ". . . It made a twisting motion as it sped along. . . ." From (54): ". . . In looking at it as it approached it would be turning anti-clockwise. . . . I have it from a number of people in different parts of the country . . . all agree on the direction it was turning." From the above notes a counter-clockwise spiral motion seems beyond question to have occurred. This would indicate that the mass had an irregular shape.

As usual, we have most varied estimates for the duration of flight. An additional complication is introduced for this fireball because most people saw only part of its path, and many confused the duration of certain other phenomena with that of the flight itself. The estimates run from 3 to 120 seconds; the average is meaningless. From the general notes, it may be inferred that the velocity was not excessive. It also seems certain that for the latter part of its path, it was throwing off sparks. The more reliable estimates of its apparent diameter, even from stations at no great distance from its path, give values of from 15′ to 30′; probably 20′ would be a good average. Of course the large linear diameter indicated by this figure is not the size of the bolide itself, but of the mass of incandescent gaseous and other material surrounding the solid nucleus. The wider part of the train about 5:20 was, however, fully 1° in diameter, which amounts to 7 or 8 km. This means that there must have been excitation of some sort fully 4 km. from the actual path, assumed as central for the train.

It is difficult to be absolutely sure whether the original

bolide, when entering the atmosphere, was a single mass or not. Certainly, along its very extended path it seems to have "exploded" many times, and, according to Nininger, to have dropped fragments, now recovered, many miles before its end point was reached. From the evidence in my hands, I tend to believe that it was a single stone which disintegrated as it passed along.

The long endurance of its train presents a complicated problem. The part that lasted longest, *i.e.*, the clouds or knots in its first half, we find are in the stratum 60 km. to 100 km., which agrees well with that defined by Trowbridge[3] believed to be the home of long-enduring trains seen at night. However, there were fainter portions of the train to the east of these brightest knots, and presumably, therefore, at a somewhat greater height. We also know that the lower or western end of the train, which faded more quickly, still lasted for many minutes, and some of its condensations were visible for at least 25 minutes, as proved by Allen's photograph.

The trains previously dealt with by me have either occurred within the stratum defined by Trowbridge or been low enough to be considered as definite smoke trains, seen after daylight. Here, however, we have a train extending nearly all the way from the upper to lower end of the bolide's path. In round numbers, the Sun was only 5° below the horizon for this upper point, only 11° below for the lower; *i.e.*, the whole path was in the twilight zone, the Sun's rays actually reaching the middle point of the path by about 6:43 C. S. T. Were the whole matter merely a reflection phenomenon, we would have expected a different distribution of brightness. Nevertheless, the twilight was so strong that the usual faint type of illumination seen at night could not alone account for the observed intensity.

In communications from Walter A. Schmidt, already quoted at length, he offers the following possible explanation, which seems to me very interesting. He says:

"I watched the smoke trail for fully an hour and a half and after the sun illuminated the smoke trail, it had quite a different appearance, changing from a phosphorescent light to a white cloud-like light.

"In our technical work we have done a very great deal of investigating in the field of electrical discharges through gases, and it seemed to me that the peculiar luminosity strongly indicated some electrical effect. I am at a complete loss to explain this, and very likely am entirely wrong, but I have been wondering whether the small particles forming the smoke trail could not have acquired electrical charges as a result of their rapid motion through the air, and that an actual electrical discharge could not have taken place between these particles in the rarified atmosphere. The charging of particles by friction is a well known phenomenon, and the individual particles might well be charged to opposite polarities, and if so a discharge in the rarified gases might well be possible. At any rate, the appearance of the light was such as to strongly suggest electrical action."

This independent explanation is interesting in the light of the work on meteor trains by C. C. Trowbridge between 1906 and 1918. A comprehensive summary of his work cannot of course be undertaken here, but some mention must be made of his general conclusions. An exclusively electrical cause for the trains (*i.e.*, discharges between particles) was discarded by him largely because of the long endurance of the luminosity. However, "it is highly probable," he believed, "that electrical effects are produced by the great velocity of the meteor and the physical changes that accompany its combustion in the atmosphere." [2] He was convinced that the phenomenon of night trains was primarily gas phosphorescence, although trains visible also in the daytime contained enough meteoric dust to reflect sunlight like an ordinary cloud. [3] His conviction was based upon much laboratory work on the afterglow produced by the electrodeless ring discharge, [4] which indicated the similarity of afterglow and meteor trains not merely on the basis of appearance, but also on the most favorable atmospheric pressures for both intensity and endurance, the rate of diffusion of the luminosity, the rate of apparent decay, and the similarity of type of spec-

trum.[5, 6] "The motion of the meteor through the atmosphere . . . may bring about chemical or physical changes in the composition of the atmosphere which on gradually reverting to its original state gives out a phosphorescent glow . . . connected with the highly ionized state of the air produced by the very high temperature of the nucleus . . . intensified by static electrical conditions . . . produced by the rush of the meteor through the air."[3]

The train of the fireball of March 24, 1933, seems to have been an example of a luminosity proceeding from a mixture of gas and extremely fine meteoric dust.[3] Mr. Schmidt's excellent and long view of the train apparently enabled him to watch while the preponderant cause of the luminosity changed from gas phosphorescence to sunlight reflection. Spectroscopic observations on this train would have been uniquely valuable. If they could have been made on selected sections of the train, they might have afforded us a definite check on Trowbridge's theory of gas phosphorescence, as that phosphorescence is limited by gas pressure and hence restricted to a relatively narrow atmospheric region.

To all of the persons mentioned in this paper, as well as to thirty or forty others whose names do not appear for lack of space, although they kindly reported observations, I express most sincere appreciation. The results obtained were possible only through their generous cooperation. I am further indebted to F. W. Smith, who as a volunteer worker at the Flower Observatory put the data in shape and made an approximate solution for the end points which greatly shortened my later work.

REFERENCES

1. H. H. NININGER. The Great Meteor of March 24, 1933, *Popular Astronomy*, **42**, 1934, p. 291.
2. MABEL WEIL. Theories on the Nature of Meteor Trains, with a Note on Professor Trowbridge's Contributions to our Knowledge of Meteor Trains, *Popular Astronomy*, **30**, 1922, p. 524. Bibliography.
3. C. C. TROWBRIDGE. The Physical Nature of Meteor Trains, *Astrophysical Journal*, Sept., 1907, p. 95.
4. C. C. TROWBRIDGE. Duration of the Afterglow Produced by the Electrodeless Ring Discharge, *Physical Review*, Oct. 1906, p. 279.

5. C. C. TROWBRIDGE. Measurements of the Rate of Decay of Gas Phosphorescence, *Physical Review*, February, 1911, p. 129

6. C. C. TROWBRIDGE. The Origin of Luminous Meteor Trains, *Popular Science Monthly*, August, 1911, p. 191.

FLOWER OBSERVATORY OF THE
UNIVERSITY OF PENNSYLVANIA

DEVELOPMENT AND CORRELATION OF RESEARCH IN PHYSICAL ANTHROPOLOGY AT HARVARD UNIVERSITY

EARNEST A. HOOTON

INTRODUCTION

CULTURE is a function of the human organism. The fact that culture is an exclusive product of the human animal is ultimately referable to some property or capacity of that organism which is either unique in man or exists only in variously rudimentary stages of development in lower zoölogical orders. Culture consists of arts, industries, social institutions, and a body of systematized and transmissible knowledge. Variations in the form and content of culture are generally ascribed to causes which may be classified broadly as environmental or ecological, since they stress the effect upon the human organism of diverse combinations of extrinsic forces rather than quantitative differences or qualitative changes in the organism itself. Thus conventional history is a concatenation of environmental events, and knowledge a codification of environmental experience.

Virtually all learning pertaining to human activity neglects the organism or proceeds upon a tacit assumption of its constancy as a factor in the production of culture. Since the organism itself is the sole producer, and the very existence of culture depends upon organic variation, this procedure is nonsensical. Social science (which is like a Welsh rarebit— not really a rabbit at all) is completely topsy-turvy when it attempts to base the interpretation of human culture upon a fundamental disregard of the variable nature of man.

Medical science, indeed, purports to advance from the study of the organism to the interpretation of its function, but actually proceeds mainly by manipulating the environment.

It courageously attempts to correct pathological deviations from unknown and fluctuating norms by a fumbling process of trial and error. Nevertheless its comparatively efficacious practice of white magic does involve a more or less conscious effort to get at the organic basis of malfunction.

Anthropology began with the collection of material and immaterial curios pertaining to man, gathered by inquisitive and acquisitive persons. It was completely devoid of any specious pretense of utilitarianism, such as appertains to most established branches of knowledge. Its practitioners, at best, were groping for a better knowledge of man, with a passive, *ex post facto*, historical attitude. The evolutionary hypothesis provided a much needed orientation for anthropological studies. It involved the conception of a changing organism related in some fashion to its increasingly complicated cultural environment. Ultimately there grew up a vague belief that anthropology has something to do with modern life—that the study of the primitive and the savage may afford a basis for the interpretation of advanced and civilized society, that a preliminary essay in the investigation and comprehension of the simple may supply the essential prerequisite for a solution of the complex. From this stage anthropology has progressed until it presently may lay claim to the status of an applied science—a system of investigation and analysis with the very broadest viewpoint from which to appraise the shortcomings of civilization and to suggest remedial measures.

In its inception, physical anthropology was a pure science in the sense of being completely useless. As an avocation of anatomists and zoölogists, it concerned itself principally with evolutionary origins, and indulged a somewhat ghoulish preoccupation with osseous remains. In the hands of myopic specialists it tended to an industrious but unintelligent accumulation of metric data relating to the gross dimensions of bones or of living subjects, together with exhaustive description of the minutiæ of anatomical variations, lacking point and precision. The realization of the possibilities of

physical anthropology as an applied science is as yet incomplete even among its practitioners.

The unification of all anthropological subjects was originally due to the diffuse dilletantism of those interested in the remote places of man's past and present. With the development of organized departments of anthropological teaching and research, this initial generalization has tended to break down into the pursuit of numerous microscopic and anchoristic fields of specialization: linguistics, technology, ethnology, ethnography, archæology, osteometry, anthropometry, social anthropology, and what not. However, it is now becoming clear that anthropology cannot be dismembered without sacrificing its potentialities as an applied science which is at once biological and social.

This paper is intended to exemplify the development of a clear concept of the nature and function of physical anthropology—theoretical and applied—by its evolution and correlation with other studies of man in one institution over a period of twenty-two years. It illustrates the progression from a microscopic to a cosmic conception of the biological study of man, such as is taking place everywhere. It is not to be regarded as a record of achievement, but rather as a "sharing" (in the Buchmanite sense) of sins of omission and commission partly due to ignorant misconceptions of the writer and partly due to the inchoate state of an incipient science. Learning has been by the trial and error method of the lower animals rather than by an ideational solution based upon a survey of the complete layout—such as is supposed to be characteristic of man and the anthropoid apes.

Early Isolated Efforts and Sporadic Attempts at Correlation and Application

In the pre-war period the first research efforts of a physical anthropologist attached to a museum were likely to be studies of skeletal remains deposited by archæologists as a result of their excavations. The job of the physical anthropologist was to describe these remains and to make some sort of a

racial diagnosis. Usually the archæologist prepared and
published his report without any reference to the skeletal
finds. Most were so conscious of their virtue in preserving
the bones that they considered their scientific responsibilities
fully discharged when the skeletons had been dumped in a
museum. The present writer undertook several such tasks—
mostly relating to the bones of American Indians. From
them he learned the folly of dissociating excavation reports
from the study of the skeletal material which they produce.
One example will suffice. The Peabody Museum excavated a
large Indian cemetery at Madisonville, Ohio, in spasmodic
efforts beginning in 1882 and ending in 1911. It devolved
upon this unfortunate to study the bones. In order to make
such a study intelligible, he was forced to spend an entire
summer struggling with the field notes and records of three
generations of archæologists who had worked the site. He
had to patch together by collation and speculation some sort
of consecutive account of the excavations. All evidence as
to the relative ages of the different portions of the cemeteries
had been lost, and stratigraphy was absent or unrecorded.

The physical anthropologist had to content himself with a
consideration of the remains as of one period. Apart from the
mere description of the bones, the only advance in anthro-
pological method resulting from this effort was a fairly suc-
cessful attempt to deduce the size of the population and its
probable annual death rate from an examination of the
proportions of each age and sex represented in the skeletal
material.[1]

In 1914, Oric Bates, a brilliant young Africanist recently
appointed curator of that field in the Peabody Museum,
projected an ambitious series of annual volumes to be called
"The Harvard African Studies." His enthusiasm enlisted
the coöperation of the present writer. Mr. Bates died in 1918,
before the second volume of his series had gone to press,

[1] Hooton, Earnest A., "Indian Village Site and Cemetery near Madisonville,
Ohio," With Notes on the Artifacts by Charles C. Willoughby. Papers of the Peabody
Museum of American Archaeology and Ethnology, Harvard University, Vol. VIII,
No. 1, pp. 1–137, 1920.

leaving the responsibility of editing the series, which now comprises ten volumes, upon the inadequate shoulders of his younger colleague. The first field effort incidental to the production of this series was an expedition to the Canary Islands, designed to clear up the much argued question of the affinities of the Guanches, an extinct race of cave dwellers alleged to be remnants of the famous Cro-Magnon artists of Upper Palæolithic Europe. Upon this expedition the writer was forced to gather his own data, both physical and archæo-logical. The skeletal remains from each of the seven islands of the group had to be associated with the respective cultures of the archipelago, and it was necessary to work out a consistent explanation of migrations and a correlation of racial types with material culture. On the purely physical side this project contributed largely to the education of the immature worker. It taught him that the analysis of a racially mixed population, whose antecedents are individually unknown, can best be approached by the division of skull series into morphological impressional types, on the basis of general resemblance. Such types may then be validated by statistical tests. This effort also illuminated (for the writer) the vexed problem of the combination of cranial characters in racially mixed types. On the whole, this study seemed to confirm the necessity of an intimate coöperation of the archæologist with the physical anthropologist.[2]

In 1915 the Department of Archæology of Phillips Academy, Andover, began the excavation of the great Indian pueblo at Pecos, New Mexico, under the direction of Dr. A. V. Kidder. The pueblo was occupied continuously for a period of at least six hundred years. In the rubbish heaps Dr. Kidder found evidence of eight cultural phases stratigraphically superimposed. It was my privilege to undertake the study of the skeletal remains yielded by these excavations— the largest series from a scientifically excavated, stratified site of the New World. Having profited by the errors of earlier

[2] Hooton, Earnest A., "The Ancient Inhabitants of the Canary Islands," *Harvard African Studies*, Vol. VII, 1925.

workers, Dr. Kidder arranged to have the physical anthropologist assist in the actual excavation during at least a portion of that activity. The summer of 1920 was so spent by the writer. This study of nearly one thousand human skeletons showed a continuity throughout the various archæological strata of the various cranial types present from the beginning, although with some tendency for certain types to amalgamate their morphological characteristics and for all of the stock to deteriorate. It afforded opportunity for elaborating and perfecting the method of type identification begun with the Canary Island series. It also led to an attempt to determine the racial affinities of the various fundamental cranial types of the Southwestern United States, and to the setting up of a tentative scheme of the sequence of migrations of Asiatic stocks into the New World in prehistoric times.[3]

Prior to the completion of the Pecos study and thereafter, a number of skeletal investigations have been carried out in the Harvard Anthropometric Laboratory along lines laid down by the Canary and Pecos researches. Among the more important of these are Dr. W. W. Howells' study of crania from Mimbres,[4] New Mexico, and Dr. Carl C. Seltzer's report on a series of crania and bones of Mediæval Icelanders gathered by V. Stefansson. The latter study, still unpublished, is of particular interest in that it shows certain bodily modifications in the ancient Icelanders which are probably attributable to their restricted diet. It also furnishes clear indication of a stronger Irish element in the Icelandic population than has been admitted by historians and anthropologists. A marked inferiority of size characterizes the Mediæval Icelanders as compared with the modern inhabitants of the island.

PURSUIT OF SPECIAL PROBLEMS IN APPLIED ANTHROPOLOGY

There is at least one problem of physical anthropology which so intimately concerns the present and future welfare of

[3] Hooton, Earnest A., *The Indians of Pecos Pueblo, A Study of Their Skeletal Remains*, New Haven, Yale University Press, 1930.

[4] Cosgrove, H. S and C. B., "The Swarts Ruin" (with a section on the skeletal material by William White Howells), Papers of the Peabody Museum of Archæology and Ethnology, Vol. XV. No. 1, pp. 115-173, Cambridge, 1932.

modern nations that its study requires no apologia.   Race
mixture raises the question of the inheritance of physical
characteristics in the hybrid offspring, as well as their fertility,
vitality, intelligence, and capacity for civilization.   The
importance of investigating these phenomena impressed itself
upon the writer almost at the outset of his professional career.
The studies in race mixture carried on by Harvard colleagues
and pupils have already been made the subject of a communi-
cation to the American Philosophical Society.[5]   In the
beginning Professor A. M. Tozzer undertook the gathering of
anthropometric data upon some five hundred Hawaiian
subjects of pure and mixed blood.   This work was begun in
1916 and the results were finally published by Dr. Leslie C.
Dunn in 1928.[6]   In 1923 a fellowship granted by the Bernice
P. Bishop Museum of Hawaii made it possible for Dr. Harry
L. Shapiro to embark upon a study of the descendants of
mutineers of the British warship, *Bounty*, and Tahitian
women—a famous and historic case of race mixture.   A
storm prevented Shapiro from landing on Pitcairn, but he was
able to reach Norfolk Island and to study for five months the
larger body of the *Bounty* descendants domiciled there, and to
produce an authoritative report upon their physical and
sociological characteristics.[7]   Dr. Shapiro, for some years
Associate Curator of Physical Anthropology at the American
Museum of Natural History, has just returned from a suc-
cessful expedition to Pitcairn Island made some eleven years
after his visit to Norfolk.   It is a pleasure to state that the
Harvard Anthropometric Laboratory has already completed
the statistical reduction of Dr. Shapiro's data on the complete
series of Pitcairners, and that the sequel to his admirable
Norfolk monograph may be expected shortly.

[5] Hooton, Earnest A., "Progress in the Study of Race Mixtures with Special Refer-
ence to Work Carried on at Harvard University," *Proceedings of the American Philo-
sophical Society*, Vol. LXV, pp. 312–325.

[6] Dunn, Leslie C., "An Anthropometric Study of Hawaiians of Pure and Mixed
Blood," Papers of the Peabody Museum of American Archæology and Ethnology,
Vol. XI, No. 3, pp. 90–209, Cambridge, 1928.

[7] Shapiro, Harry L., "Descendants of the Mutineers of the Bounty," Memoirs
of the Bernice P. Bishop Museum, Vol. XI, No. 1, pp. 1–106, Honolulu, 1929.

In 1919 Caroline Bond Day, a student of Radcliffe College of mixed Negro and White descent, began to gather anthropometric, genealogical, and sociological data upon mulatto families of the United States. This work went on intermittently for a number of years and resulted in a large and invaluable collection of photographs and records pertaining to more than three hundred families. A part of this material has been published as a monograph of the Harvard African Studies.[5]

Another important piece of work was carried out by Dr. George D. Williams in Yucatan. Here in an extensive study of the results of crosses between Maya Indians and Spanish, Dr. Williams succeeded in showing the relationship between advance in social and economic status and progression from Indian to European combinations of physical features. He also made some fundamental contributions to the physiology of racially mixed types with respect to blood grouping and basal metabolism.[9]

In 1928 Frederick S. Hulse, another young physical anthropologist, was sent to Cuba to investigate the pure and mixed races of that island. This work revealed the necessity of studying the Spanish population in its home country in order to appraise the possible changes in physical status which have taken place in the descendants of Spanish immigrants to the New World. The results of this study have not yet been published.

The most recent Harvard study of race mixture was conducted by Martin Luther in Southern Greenland. There, in 1929, Mr. Luther secured invaluable data on the crosses of Danes and Eskimos, whereby he was enabled to segregate and investigate the hybrid types according to proportions of European and Eskimo blood. In this particular cross there is a definite regression of physical features upon amount of

[5] Day, Caroline Bond, "A Study of Some Negro-White Families in the United States," *Harvard African Studies*, Vol. X, Varia Africana V, Cambridge, 1932.

[9] Williams, George Dee, "Maya Spanish Crosses in Yucatan," Papers of the Peabody Museum of American Archæology and Ethnology, Vol. XIII, No. 1, pp. 1–256, Cambridge, 1931.

European blood, and the hybrid culture developed is of the very greatest interest.

In general these studies of race crossing seem to show no biological inferiority of racial hybrids, little or no heterosis or hybrid vigor, but a heightened fecundity, a segregation of inherited traits, the presence of multiple factors in their inheritance, and the impossibility of simple Mendelian interpretations. However, it is clear that the most important aspect of race mixture is the social selection of types which operates in favor of those showing a preponderance of the physical features of the superordinate race.

The most extensive study in applied physical anthropology hitherto attempted at Harvard is the survey of the relation of race and nationality to crime in the United States, begun in 1926 and now in the final stages of analysis. This is nothing less than an inquiry into the possible connection between physique and social behavior, as manifested in the convicted felons of ten states. A preliminary report upon one phase of this work has been presented to this society.[10] That mass of data includes some one hundred and twenty-five sociological and anthropological statements concerning each of seventeen thousand individuals treated by race, by nationality, and by nature of offense. The results of the survey are the most socially important of any anthropological study thus far conducted by Harvard University, and are of such a revolutionary nature that they must not be published without validation by a complete presentation of the supporting data. On account of the high cost of publishing a large body of statistical matter, there is no present prospect of making this criminological material available for use. In very general terms it may be stated that all races and nationalities of criminals represented in this survey are physically inferior to the corresponding classes of law-abiding citizens; that criminals of any given race or nationality are as groups physically

[10] Hooton, Earnest A., "Preliminary Remarks upon the Anthropology of the American Criminal," *Proceedings of the American Philosophical Society*, Vol. LXXI, No. 6, pp. 349–355, Philadelphia, 1932.

differentiated according to the type of their offense; that crime is the resultant of a complex but perfectly intelligible process of biological and sociological forces whereby mentally and physically inferior individuals of every race and nationality are selected for delinquency. Nevertheless these statements, and the practical suggestions deducible from them, can carry little weight until the evidence of their validity is available.

The application of physical anthropology to social problems of to-day has been illustrated by the foregoing sociophysical studies. There has been opened a wide vista of unrealized possibilities of a practical utilization of physical studies of man. One further study of this category may be mentioned. In 1929 Mr. Gordon T. Bowles undertook an analysis of the physical changes in the sons and grandsons of Harvard men, based upon gymnasium records of three generations. The results showed a progressive modification in bodily dimensions and proportions, in the direction of increased stature and accentuated slenderness. This brief cut-out of a continuous film of human evolution in this country cannot yet be interpreted in its exact connotation.[11]

EXTENSION OF PHYSICAL ANTHROPOLOGICAL STUDIES TO NATIONAL GROUPS

The extension of physical studies of special sociological groups, or of tribes and peoples, to those of entire national groups naturally followed upon the mechanization of processes of statistical reduction in the laboratory. As long as anthropometric data had to be elaborated by hand, really adequate samples of populations could not be acquired, simply because their analysis involved an impossibly laborious task of arithmetical drudgery. The Harvard Criminal Survey necessitated the introduction into the laboratory of electric calculating machines, and electric sorting and tabulating apparatus. This equipment removed the limitations of sampling imposed by primitive methods of reducing data. There followed a period of intensive field work in which

[11] Bowles, Gordon T., *New Types of Old Americans at Harvard*, Cambridge, 1932.

investigators from the Harvard Laboratory gathered large masses of material pertaining to the physical and sociological characteristics of peoples or groups, little known, or inadequately studied. Notable among these are Dr. Carleton S. Coon's great anthropometric and ethnographic study of the tribes of the Rif, Morocco, which included a successful correlation of physical characteristics with material culture and social organization,[12] the same investigator's extensive survey of the tribes of Albania, completed but still unpublished for the usual financial reason, and finally his work on the peoples of Southern Arabia, still in process of analysis. Of particular importance is Mr. Martin Luther's study of the Finns, which began with a mainly physical survey of the colony of Lanesville, Massachusetts, was continued in the gathering of a large anthropometric sample and appropriate sociological data upon the Finns of Finland, and has now developed into a gargantuan functional and historical study of the entire population of Cape Ann, nearly completed. Another very considerable achievement in the field of racial analysis is that recently accomplished by Gordon T. Bowles during two years of field work as Harvard-Yenching Fellow in Eastern Tibet and Szechuan Province of Western China. This work demonstrates among other elements a strong Caucasoid strain in the inhabitants of Eastern Tibet and in the non-Chinese tribes of Western China, hints at a submerged Australoid or pre-Dravidian element, and clearly indicates that the center of differentiation and dispersion of the true Mongoloid physical type is not on the central Asiatic plateau, but probably somewhere to the north in the Siberian plains. Dr. Bowles has just departed to continue along the southern slopes of the Himalayas his studies of Tibetans and peoples peripheral to the Tibetan plateau. As a continuation of the interest in the origin of the Dinaric and Armenoid racial types, Mr. Robert W. Ehrich has gathered an extensive series of measurements and observations upon the Montenegrins, Mr.

[12] Coon, Carleton S., "Tribes of the Rif," *Harvard African Studies*, Vol. IX, Cambridge, 1931.

Walter B. Cline a mass of data on the Syrians. The latter group has been analyzed by Dr. Carl Seltzer and is ready for publication when funds permit. Under Dr. Coon's inspiration, a series of anthropometric records of Armenians in this country has been collected and studied by the students of the course in Field Methods. One of the most competent members of this group, Mr. Byron Hughes, is actively engaged in pursuing this effort further.

Dr. Carl Seltzer began his studies of the American Indian by analyzing the mass of data on the Eskimo collected many years ago by the explorer Stefansson.[13] He has continued in the Southwestern United States by securing the largest series hitherto collected of Zuni, Hopi, Navajo, and Yaqui. The material of these studies is in process of reduction and it is hoped that this talented investigator may be enabled to continue his studies of living Indian groups for the next decade. Worthy of mention also are Dr. John P. Gillin's anthropometric and social anthropological studies of the Caribs of the Upper Barama River, British Guiana, soon to be published, and the large series of native Australians measured and observed by Professor W. L. Warner and analyzed by Dr. W. W. Howells.

One of the most extensive and promising efforts of the Laboratory has been in connection with A Century of Progress Exposition at Chicago during the summers of 1933, 1934. Harvard University was asked to equip and operate an anthropometric laboratory in the Hall of the Social Sciences for demonstration purposes. The laboratory was fitted out gratuitously through the cooperation of the commercial firms which have equipped the Harvard Laboratory. The staff was detailed from that of the Harvard Laboratory under the leadership of a very able physical anthropologist, C. W. Dupertuis. At the Exposition, methods of measurements and the use of the apparatus for statistical analysis were demonstrated. The exhibit was thronged through the period of its

[13] Seltzer, Carl C., "Anthropometry of the Western and Copper Eskimos, Based on Data of Vilhjalmur Stefansson," *Human Biology*, Vol. X, No. 3, September 1933.

operation and more than six thousand individuals were subjected to a complete series of anthropological measurements and observations. This series, now in process of analysis, should constitute the most valuable sample of the native American population of moderate means heretofore gathered, since it consists of adults of both sexes in approximately equal proportions.

All of the foregoing studies of national groups are principally oriented toward racial analysis with secondary sociological data for correlation purposes.

STUDY OF COMPLETE NATIONS

The ultimate purpose of the anthropologist is to provide a complete interpretation of the human animal in his environmental setting. The development of physical anthropological studies at Harvard and the advance of research in other anthropological fields have resulted in progressive encroachments of each specialty upon the preserves of the others, in order to secure significant explanatory data. Thus the archæologist is driven further and further into interpretation of his cultural data in connection with skeletal material; the physical anthropologist finds himself perforce delving deeper and deeper into the collection and correlation of sociological data or of archæological facts; the ethnologist advances steadily into the fields of his colleagues for the same reason. It is a significant fact that almost none of the anthropologists recently trained at Harvard can be forced to relinquish to their specialist colleagues the data in allied fields which they themselves have collected in expeditions. Thus the archæologist insists upon working up the skeletal material which he has exhumed; the ethnologist prefers to correlate his own anthropometric data with his cultural findings, and the physical anthropologist raids in all directions and utilizes his miscellaneous booty. Such a development is most healthy and is especially efficacious in studies of comparatively small groups or cultures carried on by one individual. In the case of more ambitious problems involving consideration of very

large groups, a division of labor is essential, but the extension
of interests on the part of each specialist insures an ultimate
correlation of the data collected in the respective fields.

Perhaps the first tentative essay at a general anthro-
pological interpretation of a country, so far as Harvard
anthropology is concerned, was the study of the Hinterland
tribes of Liberia, undertaken by Mr. and Mrs. George Schwab
and by Dr. George W. Harley. This effort was a direct
outcome of the need for information on the part of the joint
committee on Protestant missions which administers American
work in Liberia, the educational adviser to Liberia, and the
Firestone Tire and Rubber Company. The results of this
work include: (a) a practical report to the missions committee
on the status of education and religious activity in the
country; (b) a similar report to the Firestone committee
dealing with economics and labor problems; (c) a voluminous
scientific treatise including an exhaustive ethnographic survey
of four interior tribes with comparative data on remaining
tribal groups, adequate anthropometric samples from each of
these four tribes, and a special study of some six thousand
cases from the medical clinic of Dr. Harley at Ganta, Liberia.
Unfortunately this huge mass of material remains unpublished
for the usual reason—lack of funds.

Experience with the Liberian project and others indicated
the necessity of a more general set-up for any anthropological
study which pretends to deal with a whole nation. Some
three years ago it was decided to undertake an anthropological
study in Siam, following the trail broken by Professor Carle
C. Zimmerman of the Division of Sociology of Harvard
University. This investigator had carried out an economic
survey of rural Siam under the auspices of the Siamese
government. Through Dr. Zimmerman's Siamese connec-
tions, it was possible to induce the Siamese government to
make a more extensive medical, anthropological, economic,
and ethnographic survey under the direction of a young
Harvard anthropologist, James M. Andrews. The field work
of this project has been completed after two years of effort.

Mr. Andrews had charge of a party of thirty-five Siamese field investigators who went from district to district studying sample villages in each. More than forty villages were included in the survey. In each the entire population was subjected to an anthropometric and medical examination and very detailed schedules were filled out pertaining to economic and ethnographic status. The results of this study should afford the Siamese government the necessary information for the reorganization and extension of its department of public health and for certain essential developments of its marketing and agricultural system. Incidentally it will provide, for the first time, a firm basis for the appraisal of racial and ethnological status of this interesting country. The huge mass of data resulting from this survey is, as yet, unreduced.

The ultimate realization of slowly crystallizing ideals of anthropological correlation is the Harvard Anthropological Survey of Ireland. This is an audacious attempt to interpret an entire civilized nation through a simultaneous study of its prehistoric and historic archæology, the examination of the skeletal remains of its past population, an anthropometric survey of its modern population, and an intensive study of its social organization in one typical county, fortified by samplings in other areas. This survey was organized under the writer, acting for the Division of Anthropology and the Peabody Museum of Harvard University. The archæological work is under the direction of Dr. Hugh O'Neill Hencken, assisted by Mr. Hallam L. Movius, Jr. The social anthropological survey is in charge of Professor W. L. Warner. The archæological and social anthropological portions of the research program were first put into operation. The fourth archæological expedition is about to take the field. During the three previous seasons, excavations carried on by Dr. Hencken and his associates have included that of the supposed classic site for Palæolithic remains, Kilgreany Cave, County Waterford (which proves not to be Palæolithic after all); several raised beach Mesolithic sites, mostly in County Antrim, together with later Neolithic sites; a number of Bronze Age tumuli, an

Iron Age fort, and three Late Iron Age lake dwellings or crannogs. All objects recovered become the property of the Irish Free State or of the Ulster government. The work is carried on under the auspices of the National Museum in the Free State and of the Belfast Museum in Ulster. During the past season the Free State furnished archæological laborers under its unemployment relief scheme.

The social anthropology has concentrated upon an intensive analysis of County Clare by Professor Warner and his associates, Dr. Conrad Arensberg and Mr. Solon Kimball. The last two investigators have completed the gathering of data pertaining to every phase of social life in this county, together with necessary comparative material from other Irish areas.

The physical anthropological survey has been operating for a little more than six months. Adequate anthropometric samples are being gathered in each county by Mr. C. W. Dupertuis, who has already measured and observed more than four thousand individuals. This summer it is planned to add to the anthropometric staff a specialist on skeletal remains who will examine a large series of burials from a certain very rich site, and a woman anthropologist who will undertake the measurement of Irish females and juveniles.

It should be noted that this survey has had, from the beginning, the most enthusiastic support and the fullest coöperation of the government of the Irish Free State, the learned societies and scientists of that country, and, in fact, of every element in the population. Coöperation in Ulster has been equally gratifying. The organizers of this project have high hopes of the ultimate production of something approximating a complete anthropological history of Ireland.

SUMMARY

This paper has concerned itself primarily with an account and illustrations of the evolution of the conception of the scope and function of physical anthropology at one institution. It has not considered many by-products of this process, such as

numerous small researches dealing with the improvement of technique and special problems of physical anthropology, nor the interesting process of standardizing and mechanizing the recording and statistical reduction of anthropometric data.

The foregoing account has attempted to show how physical anthropology in this institution began with the performance of miscellaneous odd jobs on skeletons left over from archæological excavations, how it proceeded next to the analysis of much larger skeletal series in direct correlation with the archæological cultures from which they emanated; how the anthropometry of the living was initiated by studies of special biological groups of some particular sociological interest, and extended further to the consideration of the physical features of entire national groups; how finally there has come about the conception that the completely satisfactory correlation of anthropological studies can be effected only by a simultaneous and coördinated attack upon any large problem by every kind of anthropological specialist available.

Neither physical anthropology nor any other kind of anthropology can be usefully prosecuted *in vacuo*. The various phases of man's organism and his behavior cannot be dissociated from each other. I envisage a social science of the immediate future in which great problems will be studied not only by all varieties of anthropologists working in unison, but also, with them, sociologists, economists, historians, legal experts, psychologists, physicians, geographers, zoölogists, botanists, bacteriologists, and even students of government and education.

Warning should be given that the synthesis of such coöperative studies will be time-consuming and expensive. One of the most crucial differences between a scientist and a politician is that the former insists upon investigating causes of social illness before prescribing remedies, whereas the latter feels impelled to administer copious and potent doses of whatever medicine he can lay hands upon, in order to perpetuate the confidence of his gullible patients.

The lay patrons of the sciences, exact and inexact, natural

and social, should be educated to realize that final answers to great problems cannot be bought for cash down with delivery guaranteed within thirty days. Scientists are not purveyors of manufactured commodities of standardized output. They can but work out successive series of approximations to the truth and recommendations based upon incomplete and faulty analyses of stupendously intricate problems. The cutters of Gordian knots succeed only in damaging the ox-cart and leaving a hopeless tangle of loose ends. Finally, it may be stated that millions for research and not one cent for publication is a policy which condemns scientists to the punishment of the daughters of Danaus—a perpetual pouring of water into sieves.

GENIC BALANCE, SEX–DETERMINATION AND SELECTIVE FERTILIZATION IN HYMENOPTERA

P. W. WHITING

GENETIC investigations within the last decade have established the principle that the hereditary control in development of organisms depends upon balance of genetic factors or genes. It is the ratios existing among these hereditary units and their relative potency that determine whether a certain trait or group of traits shall become manifest. Absolute quantity of genic material is not the deciding factor in a growing organism since this fluctuates with cell growth and division.

While this theory of genic balance on a ratio basis may be applied to most animals, there exist numerous examples in which the type of sex-determination has hitherto appeared irreconcilable with this principle. Among these supposed exceptions may be mentioned many aleurodids, coccids, thrips, mites and rotifers as well as the entire order *Hymenoptera*, from the sawflies, chalcis-flies and ichneumon-flies to the bees, wasps and ants. The feature possessed in common among these forms, which has baffled students of sex-determination, is the fact that the males, being produced by haploid parthenogenesis, have but a single set of chromosomes, while the females, coming from fertilized eggs, have the double set. Since it has been generally assumed that the two chromosome sets of the female (2N) are each identical with that of any given male (1N), the ratio among the genes should be the same in both sexes.

Various authors have therefore attempted to solve the problem by hypotheses based on quantitative rather than qualitative relationships and have abandoned the theory of genic balance. Such explanations are admittedly inadequate. Genetic and cytological studies on the parasitic wasp *Habro-*

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bracon have further demonstrated the inadequacy of quantitative hypotheses, for it has been shown conclusively that certain males from fertilized eggs are diploid (4, 5, 7, 14).

After study of certain sex-intergrades occurring among mosaic males of *Habrobracon* (13), a complementary theory of sex-determination was tentatively advanced (8). These sex-intergrade mosaic males possess structures somewhat resembling female genitalia which are presumably caused to develop by interaction of two types of male tissue genetically different for sex-determining factors. Since such sexually diverse tissues may occur in a single mosaic male, it was postulated that two correspondingly different types of males also exist. The theory, as it has since been developed, may be briefly stated as follows:

Females are diploid and digametic possessing two different sex-chromosomes, X and Y, and a double set of autosomes, 2A. They produce from unfertilized eggs two different types of males, $X + A$ and $Y + A$, in equal numbers. These males are phenotypically indistinguishable.

The X-chromosome is assumed to contain one or more dominant factors necessary for the production of a female. This factor or group of factors may be designated F. The Y-chromosome is assumed to have another dominant female-producing factor or group of factors which may be designated G. Thus X contains F.g while Y contains f.G. A complementary action takes place between F and G in female determination, while each of the two different types of males F.g and f.G, differs from the female by one or more different recessive factors.

If the egg is fertilized by a sperm from an $X + A$ male, there may be produced a female, $X + Y + 2A$, or a diploid male, $2X + 2A$, according to the composition of the egg nucleus. Similarly sperm from a $Y + A$ male may result in diploid males, $2Y + 2A$, in addition to females.

Investigations carried out for several years have shown that diploid males are relatively inviable and are produced only if parents are closely related (1, 6, 12). If parents are

from diverse stocks, however, all offspring from fertilized eggs are females. Selective fertilization must occur, the homeosyngamic combinations (X + A with X + A or Y + A with Y + A) failing to take place, as demonstrated by experiments involving egg counts (3). There is no selection against either type of sperm with respect to penetration of the egg, but the genetic constitution of the sperm nucleus within the egg has a selective effect upon the maturation process determining which sex-chromosome, X or Y, shall be eliminated in the polar bodies and which shall remain in the reduced egg nucleus to take part in syngamy.

Genetic proof of this theory of sex-determination (2, 9) has been by means of the recessive factor fused, affecting antennae, tarsi and wings of the mutant type. Heterozygous daughters, FuY/fuX, of a single recessive male, fuX, were crossed with a fuX male. Had the factor been non-sex-linked, wild-type and fused daughters should occur in approximately equal numbers. Complete sex-linkage would result in no fused daughters. Actually about ten percent of the females were fused while ninety percent of the diploid males were fused. Crossing-over had therefore occurred between the gene for fused and the region of the chromosome concerned with sex.

(FuY/fuX crossed with fuX produces
females: 90% FuY/fuX, 10% fuY/fuX,
diploid males: 10% FuX/fuX, 90% fuX/fuX,
haploid males: 90% FuY,   10% FuX,
               10% fuY,   90% fuX.)

The normal female chromosomal complex is not merely the doubled set corresponding to that of any given haploid male, X + A or Y + A, for this produces a diploid male, $2X + 2A$ or $2Y + 2A$. The female has the sum of the chromosome sets, X + Y + 2A, characteristic of the two types of haploid males.

A full account of sex-determination in bees and wasps has

recently been presented (11) and the subject of selective fertilization has been reviewed (10).

LITERATURE CITED

1. BOSTIAN, C. H., 1934. Biparental Males and Biparental Ratios in *Habrobracon*. *Biol. Bull.*, **66**: 166–181.
2. ——, 1935a. Sex-linkage as Shown by Biparental Males in *Habrobracon*. *The American Naturalist*, **69**: 57–58.
3. ——, 1935b. Biparental Males and Hatchability of Eggs in *Habrobracon*. *Genetics*, **20**: 280–285.
4. TORVIK, MAGNHILD M., 1931. Genetic Evidence for Diploidism of Biparental Males in *Habrobracon*. *Biol. Bull.*, **61**: 139–156.
5. TORVIK-GREB, MAGNHILD. 1935. The Chromosomes of *Habrobracon*. *Biol. Bull.*, **68**: 25–34.
6. WHITING, ANNA R., 1925. The Inheritance of Sterility and of Other Defects Induced by Abnormal Fertilization in the Parasitic Wasp *Habrobracon juglandis* (Ashmead). *Genetics*, **10**: 33–58.
7. ——, 1927. Genetic Evidence of Diploid Males in *Habrobracon*. *Biol. Bull.*, **53**: 438–449.
8. WHITING, P. W., 1933a. Sex-determination in *Hymenoptera*. *The Collecting Net*, Woods Hole, **8**: 113, 121, 122.
9. ——, 1933b. Selective Fertilization and Sex-determination in *Hymenoptera*. *Science*, **78**: 537–538.
10. ——, 1935a. Selective Fertilization. *Jour. Heredity*, **26**: 17–22.
11. ——, 1935b. Sex-determination in Bees and Wasps. *Jour. Heredity* (in press).
12. WHITING, P. W., AND RUSSELL L. ANDERSON, 1932. Temperature and Other Factors Concerned in Male Biparentalism in *Habrobracon*. *The American Naturalist*, **66**: 420–432.
13. WHITING, P. W., RAYMOND J. GREB AND B. R. SPEICHER, 1934. A New Type of Sex-intergrade. *Biol. Bull.*, **66**: 152–165.
14. WHITING, P W., AND ANNA R. WHITING, 1925. Diploid Males from Fertilized Eggs in *Hymenoptera*. *Science*, N.S., **62**: 437.

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ASPECTS AND IMPLICATIONS OF THE HORMONAL CONTROL OF THE MATERNAL INSTINCT

OSCAR RIDDLE

I

"But intelligence does not spring into being fully armed from the head of Zeus. It is born within the sphere of instinct, and at first grasps only a little of what instinct prompts." Hobhouse, Mind in Evolution, London, 1915.

EXPERIMENTAL results obtained in association with Dr. Robert W. Bates and Mr. Ernest L. Lahr have shown that the maternal instinct in virgin rats (1, 2), also the incubation instinct in fowl (3, 4), is under the immediate control of prolactin—prolactin being a hormone secreted by the anterior pituitary gland. In the present paper it is our purpose to note four points at which this demonstration of the dependence of an instinct upon a hormone contributes to theory of development, animal behavior and psychology.

A word should be said at once concerning the nature of the activities evoked in the virgin rat by injections of the hormone.[1] These activities comprise nest-building over young, carrying young to the nest, and cuddling or caring for young in the nest. Young rats, young mice or newly hatched pigeon squabs are treated in this manner after injections, though quite neglected prior to the injections. It seems fairly clear, though positive experimental evidence is still needed, that the primary motivation of *all* these activities comes from within rather than without; and we are fully convinced that, though the activities induced by our brusk

[1] A moving picture film illustrating this point was shown at the Detroit meeting of the Federated Societies of Experimental Biology, April 11, 1935; also at the meeting of the American Philosophical Society at which this paper was read, April 19, 1935. The film is to be shown at the International Physiological Congress, Moscow, August, 1935.

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injections of prolactin are usually less in intensity than those
following normal motherhood in the rat, they are qualitatively
the same. This same statement applies to the prolactin-
induced behavior (incubation) and maternal care obtained in
the fowl. Again, we hasten to note that the convenient word
"instinct" is used here to indicate an elaborated response—
not a simple reflex—which can occur without previous
learning, conditioning or habit formation.

II

To theory of development it is significant that a hormone
has been found to act upon a variety of tissues and processes,
and at the same time to maintain an underlying unity of the
several responses it evokes. In the present case the various
responses are concerned with the feeding and care of young.
Prolactin was earlier known to induce the secretion of milk
from fully prepared mammary tissue, to cause the develop-
ment of the crop-gland (gut tissue) and "crop-milk" formation
in pigeons, and to reduce the amount and activity of the
germinal tissue (possibly this is an indirect response)—both
testis and ovary—in birds during the period when eggs and
young of these animals were being incubated and reared (a
cessation of the egg producing activity is a necessity in birds if
any eggs and young are to be reared). Since the same
hormone is now found to induce the maternal instinct in rats
and fowl—thus somehow affecting nerve tissue—we here have
an instance in which a hormone acts upon *several quite different*
tissues or processes of the body; there is, however, relationship
and organization of these quite various processes, since all
center upon care and feeding of the young.

III

Observations showing that the maternal instinct normally
appears *periodically* in the animals studied, and experiments
showing that when prolactin is injected—at periods and states
quite out of step with the usual in the organism—the maternal
and incubation instincts are induced, supply some evidence

that the hormone prolactin is released from the pituitary in a periodic manner.   Other earlier studies on prolactin have indicated this same thing.   A similarly sharply delimited periodic release of a hormone having to do with developmental changes (as contrasted with maintenance) in mammals has perhaps hitherto been found only in the case of the corpus luteum hormone, and in that case the organ producing the hormone has only a temporary or periodic existence.   Since the functions of prolactin in the adult are probably not fully explored, and since the pituitaries of at least certain embryos have an unusually high prolactin content (5), it seems probable that further effects of this periodically released hormone will be found in the developing or functioning individual.   Irrespective of the outcome of further study certain aspects of cyclic behavior already find their more immediate explanation in the periodic release of prolactin.

IV

In the genetic approach to the study of behavior this elucidation of the maternal instinct also has distinction because it is perhaps that "instinctive" type of behavior which appears latest or last in the life history of the individual.   The very nature of maternal behavior identifies it with adult life. The activities associated with the sex urge—most of which are usually credited to action of the hormones of the sex glands— have necessarily preceded it.

The full power of prolactin to initiate the broody instinct in fowl, and probably also the maternal instinct in virgin rats, has been found to depend upon a previous action of the sex (gonadal) hormones.   Thus we here find—I believe for the first time in the psychic sphere—a normal development or response which rests upon a *succession* or *chain* of hormonal actions.   This succession being: estrin → progestin → pro- lactin.   This same succession was known to be concerned in the development and excitation of the mammary glands as precedent to milk secretion.   In the case of the incubation and maternal instinct in fowl (3, 4) it was shown definitely

that a full expression of the instinct could be induced only in individuals whose germ glands were actively producing the sex-hormone.

<div align="center">V</div>

The total observed maternal behavior following our hormone injections probably involves more than that which may strictly and properly be called the maternal "instinct." Not only does heredity provide a frame-work for appropriate reflexes and sensori-motor action. but persistent interest and intelligence proper—in a fairly mature and skilled animal— seem to share in the newly invoked activities.

Though the mechanism by which the hormone affects neural state or function is wholly unexplored this case provides a superior instance of somatic or extra-neural participation in a normal psychic state.   The administration of this hormone to an otherwise adequately developed rat obviously endows the animal with a quite new, normal and necessary psychological experience; and, the apparently necessary and legitimate inference from the induced activities (behavior) is that the introduction of the hormone temporarily adds to such a rat a new element of consciousness.

<div align="center">VI</div>

<div align="center">SUMMARY</div>

The hormone prolactin elicits a related series of responses though quite different tissues are involved in these responses. Despite differences in the responding tissue a unity or organization is observed in the circumstance that all responses relate to feeding or care of offspring.

Certain hitherto unanalyzable aspects of cyclic behavior find their more immediate explanation in the periodic release of prolactin from the animal's pituitary gland.

It is thought that for the first time in the psychic sphere a normal development or response is found to rest upon a succession or chain of hormonal actions.   In this case the series runs: estrin → progestin → prolactin.

In an otherwise fully equipped animal the birth of an instinct as a response to a hormone seems to warrant the conclusion that to this animal the hormone temporarily adds a new element of consciousness.

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LITERATURE CITED

1. RIDDLE, O., LAHR, E. L., AND BATES, R. W. (1935). Maternal Behavior Induced in Virgin Rats by Prolactin. *Proc. Soc. Exper. Biol. and Med.*, 32, pp. 730–734.
2. RIDDLE, O., LAHR, E. L., AND BATES, R. W. (1935). Effectiveness and Specificity of Prolactin in the Induction of the Maternal Instinct in Virgin Rats. (Abstract.) Proc. Amer. Physiol. Soc. (47th Ann. Meeting) p. 109.
3. RIDDLE, O., BATES, R. W., AND LAHR, E. L. (1935). Prolactin Induces Broodiness in Fowl. *Amer. Jour. Physiol.*, 111, pp. 352–360.
4. BATES, R. W., LAHR, E. L., AND RIDDLE, O. (1935). The Gross Action of Prolactin and Follicle-stimulating Hormone on the Mature Ovary and Sex Accessories of the Fowl. *Amer. Jour. Physiol.*, 111, pp. 361–368.
5. BATES, R. W., RIDDLE, O., AND LAHR, E. L. (1935). Concurrent Assay of Three Hormones from Anterior Pituitaries of Seven Age and Sex Groups of Cattle. (Abstract.) Proc. Amer. Physiol. Soc. (47th Ann. Meeting) p. 8.

PUBLICATION AS A SCIENTIFIC PROBLEM

J. R. SCHRAMM

THE results of research are not generally effective until published. Publication is thus the final step in that long sequence involved in the cumulative advance of knowledge. These are commonplaces, but they serve to remind us that facilities sufficient to publish the creditable work with necessary completeness, but no more, are vital in scientific progress.

That these facilities are not adequate, at least in biology, the field to which I shall largely confine myself, or at any rate are not satisfactorily integrated with the rest of research activity, is apparent on all sides. Many journals are one, two, or even more years behind acceptances; illustrations often are poor and inadequate; material in special subjects is widely scattered, even in those fields having special journals; most of us know of meritorious manuscripts for which there is no early prospect of publication, because the necessary funds, the 5 per cent more or less of the total cost of the research, has not been assured for this final step though the 95 per cent more or less has been spent without meanwhile bearing fruit. Though not limited to this class of papers, the longer more monographic articles are especially penalized. Also, many journals place a definite limit on length of papers, and charge the excess of cost to the author. It may be that this is done partly in the hope of stimulating authors to say more in fewer words; but it does not always work out that way. It did not require a genius to think of the simple expedient of breaking a manuscript into two papers or more, which, submitted separately, may have a total length greater than that of the original one. An additional regulation in some journals,

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whether to discourage this tendency or not I do not know, is
to limit the number of papers or pages which an author may
publish in a year.

Obviously, short papers at frequent intervals do not solve
the problem. In fact, the above restrictions may have
contributed to the strong present tendency to publish early
and often. Whatever the causes (and there are to be re-
membered the yearly administrative calls for bibliographies
for annual reports), one cannot but regret the relative
infrequence of the comprehensive but not necessarily long
paper. The world of science is not waiting breathlessly to
hear each month or each several months what we individually
have been doing, especially not through the double medium of
the preliminary and the final paper covering the same ground.
It is quite content to wait for those contributions in which one
month's work is integrated with that of the next until a well
grounded whole is ready for presentation.

But this is a large and complicated subject, and we are
concerned with it here only in so far as it affects publication.
There is an important place and need for the prompt publica-
tion of short papers of limited scope. Granting this, it would
appear that our publication program should foster a tendency
in the direction of fewer and better papers, so grouped as best
to serve the various branches of science and their devotees,
and published adequately, but with the utmost compatible
economy and efficiency.

Is it too much to hope that some such general program can
be approximated? In attempting to answer this question it
will be evident at once that all these desiderata are found in
some serials, certain of them in others. In short, there is no
inherent insuperable difficulty. What seems to be required
is a thorough knowledge of the basic facts and factors and
their application,—in short, a scientific approach. Experi-
ence and knowledge already existing are probably sufficient to
serve as the basis for the needed improvement, but they
need to be mobilized, integrated, and made generally available.
The problem thus has large educational aspects. If it is to be

undertaken in a thoroughgoing way, it will call for careful and sympathetic consideration of all factors and needs, and it will aim at making readily accessible dependable information. Freedom of action must be safeguarded, but there should be provided the necessary information to permit voluntary decisions in the best interests of the science and those who cultivate it. It has been my experience that those charged with responsibility for journals are eager for comprehensive and reliable information, and deplore the lack of widely available sources. If the problems are approached objectively, and we carry over into this realm the critical detached attitude to which we aspire in research, can it be seriously doubted that progress would be made?

In this connection it is important that progress be made soon if we are to continue to publish creditable researches in reasonably complete form. Already drastic schemes for meeting the situation are being seriously considered, even proposals that printed publication be limited to well indexed abstracts. Under such plans the complete papers would be available only on special order as photographic copies of the original manuscript on deposit at a specified center.

Of the many aspects of publication, perhaps the simplest, because freest from subjective elements, is that concerned with physical form and make-up. On the other hand, it is the most technical, and much lack of understanding is abroad, even among editors. It is not to be expected that editors will necessarily inform themselves technically, but they should be aware of the relation such matters have to other broader aspects of publication, such as cost and permanence, and see that these are properly considered where, as in America, scientific journals are so generally managed by societies and research institutions rather than by commercial publishers.

Machine composition is practically universal, and contributes largely to economy. These machines are marvels, but their flexibility, great as this is, has its limits. What is the range within which these machines operate with greatest economy? Obviously this is a technical question, but it

requires a definite answer if we are to draw up typographic specifications that will result in economical printing. Printers hesitate to make unsolicited suggestions looking toward specifications better adjusted to the machine's economical capacity lest the suggestions be construed as efforts in their own behalf; but they usually coöperate if invited to do so. Also, experts representing the large manufacturers of type-setting machines are available for consultation.

A single illustration will suffice, taken, as it happens, from the monotype system. The monotype machine will handle with maximum economy not to exceed 225 characters, and then only if these are in their accustomed positions in the mechanism. Suppose, as is true of many technical journals, the typography requires ordinary Roman, boldface, and italic, each in capital and small letters. This makes 6 alphabets or 156 characters. The corresponding sets of figures add 30, or a total of 186. Necessary punctuation, accent, and kindred marks, some of which differ in Roman, boldface, and italic, with the more common special characters needed, bring the total to or beyond the maximum of 225. If now, as is often the case, small capitals also are desired, 26 characters must be added. Obviously, something must be eliminated. The printer leaves out of the mechanism the characters least used, provided that by so doing it is possible to accommodate others more essential. However the matter is adjusted technically, the operator can do no better than strike a blank when he encounters a character not in the mechanism. These missing characters must subsequently be inserted by hand from movable type, which obviously increases composition cost. Knowing this, a clearcut basis is provided for deciding whether the importance of, *e.g.*, small caps, justifies the added cost.

There is another reason for preparing definite specifications, at least in those directions in which price is materially affected, and this is that the proposals submitted by printers may be comparable. I am convinced that not infrequently, especially in the case of new or modified journals, no reliable basis exists for comparing prices, and this through no fault of the printers.

There are numerous other questions of format and typography by no means unimportant, some of them vitally affecting costs. These cannot be discussed here, but they should not be forgotten for they most certainly will turn up realistically in the bills, either to our satisfaction or to our regret, depending on how we have dealt with them. Lest there be misapprehension, however, it should be emphasized that considerations of economy and of desirable makeup do not necessarily conflict.

In scientific publications, degree of permanence of the paper is important. Only a very few fortunately situated publications can consider 100 per cent rag paper. For the great majority a paper wholly or largely of chemical wood pulp is used. What is the probable life of such papers? What should be specified to secure the best prospects of long life? Does admixture of rag increase durability? If so, how much rag is required to give added permanence? These and others are technical questions to which complete answers are not forthcoming, but some general principles have emerged, and much detailed information is available which should be utilized to insure in so far as possible that our records shall have sufficient permanence at reasonable cost.

Perhaps no single detail has given rise to more discussion than the problem presented by detailed data, especially tabular, because of the expense of composition. The suggestion that, in lieu of publication, the detailed data be deposited in some announced place where they can be consulted or photographs obtained, seems to me to have certain serious disadvantages. At least, what would seem a more convenient and feasible method has been suggested, and tried successfully. I refer to the scheme of greatly reducing the size of the necessary data by photographic methods direct from very high quality typed copy, thus substituting inexpensive cuts for extensive and costly tabular composition, and making each printed copy self-contained. True, a reading glass might be necessary for detailed examination, but is this really much of an inconvenience? Certainly, every other possibility should

be explored before we resort to the practice of dividing a publication into two parts geographically separated but both necessary for critical study of the paper, however unnecessary the detailed data for those less intimately concerned.

Possibly the same idea would apply to certain other types of material. Taxonomic papers revisional or monographic in character often devote much space to detailed records of specimens examined, sometimes accounting for over half the printing cost. Such records are valuable, but would it be unreasonable to ask those who have occasion to consult these details to do so with the aid of a reading glass, especially if by so doing it would help in more nearly balancing publication and scholarly output?

These illustrations from the physical side will suffice to indicate that a comprehensive objective approach to these problems gives promise of producing valuable results which many publications might use to advantage.

We come now to the problem of management. American scientific periodicals usually are managed directly by the societies or institutions concerned. In some cases the publications serve as an important if not the chief support of the corresponding libraries through the medium of exchange. In others, *e.g.*, national societies with no permanent institutional residence, interest is wholly in subscriptions and sales as no library is maintained. The difficulties that all these publications have faced from time to time are well known, but this may be said,—they have been maintained and at very moderate prices, partly because no profits were expected, and partly because with rare exceptions editorial services are contributed free; in short, the whole problem is to meet printing costs.

Contrary to the practice in Europe, especially Central Europe, relatively few of our publications are owned or managed, or both, by commercial publishers. The motive of a commercial house undertaking such responsibilities may be interest in science or in advertising, or a mixture of the two; but whatever the motive, this form of management usually results in higher prices, so much so in some cases that it has

become a matter of grave concern, as recent discussions in scientific and library publications testify.

Few journals owned and edited personally remain to remind us of the energy and leadership responsible for the initiation of many publications now in corporate hands. The experience of these enterprising individuals is invaluable, though the present tendency is mainly in other directions. Still another form of management is that furnished by universities, often through specially organized presses. This form probably represents a condition intermediate between society management on the one hand and conduct by commercial publishers on the other.

Finally, in a few instances in America a unique form of management has developed whereby a research institution undertakes to manage publications without disturbing editorial arrangements, either by acquiring ownership or by an agreement whereby ownership remains with the society or group. I refer to such institutions as the Wistar Institute and the Brooklyn Botanic Garden, which are rendering such service to two important groups of American biological publications. This type of management appears to offer both good fiscal arrangements and administrative experience, often not available to society publications with rotating management; also it offers a better understanding of the point of view, psychology, and needs of scientists, often inadequately grasped by commercial publishers.

Mention should be made also of a recent tendency which has an important relation to journal management. Except in institutions which maintain their own publication facilities, publication and especially its cost usually receive no consideration in research plans or programs. We seem content to hope that channels of publication will be found; usually they are finally found, but often they are inadequate, and not infrequently in inverse relation to the extent of the contribution. Since publication is an essential step in effective research, it is encouraging to note a tendency in some quarters to give it attention in planning and budgeting research, and to

consider at least a part of the cost of publication as a legitimate charge against the cost of research. Thus, a few years ago the physicists adopted a policy whereby the institution sponsoring a research is assessed an amount per page toward the cost of publication, representing not the whole cost but a contribution toward it. A special fund has been secured to meet this assessment when an institution cannot for one reason or another do so. The experience with this procedure would be illuminating in any general consideration of publication problems.

Biology contrasts sharply, perhaps unavoidably, with sciences such as chemistry and physics in that it has a very large number of journals, paralleling in large part numerous societies of which they are often the organs. Many of these represent older societies dating from a time of less marked specialization. These organizations have budded off a lusty progeny of vigorous, more specialized societies which in time have established or adopted official organs with correspondingly specialized content. Naturally, these two classes of journals cultivate more or less the same fields and to this extent overlap and compete, raising problems with which most of us are familiar. It is not our purpose here to suggest specific remedies for these problems but rather to call attention to the fact that they exist and that sooner or later they will require some solution.

There remains the very large question of the relation of the author to the general problem. This is probably the most difficult because many more individuals are directly involved, the human element enters in more immediately, and the problem of reaching those concerned is complicated. But the possibilities are perhaps correspondingly great. Dr. McClung so ably discussed this matter before Section F (Zoölogy) of the American Association for the Advancement of Science at the 1928 meeting (*Science*, Feb. 8, 1929), that it would be violating one of the sound canons he developed were I to indulge in any needless repetition of his remarks.

But in this connection I may be permitted to comment on

the concern sometimes expressed that attempts to furnish guidance in the matter of publication would be an infringement on the freedom of authors. Experience has shown that sensible suggestions are but rarely resented. This would seem to indicate that effective pertinent guidance in readily available form would fill a general need and find widespread application, with profit to authors, editors, readers, and budgets alike. Those zealous guardians of freedom, some of whom are willing to inflict heavy expense in proofs over matters no more important than the abbreviation of millimeter, would then find little occasion to spring to the defense of oppressed authors; for such guidance would rely for its effectiveness not upon compulsion but upon widespread voluntary compliance because of its obvious reasonableness and good sense.

Finally, I should like to speak for a moment to the question: Under what conditions should an author expect publication in a journal financed coöperatively, as is true of most of our journals?

It is a matter of surprise, to me at least, to find that some feel that the first consideration in publication is the author. I had assumed, perhaps naively, that the science is the first consideration, and that whether or not a particular channel of publication is open to an author is to be determined by whether the paper meets the standards as interpreted by those chosen to exercise this judgment; whether it comes within the scope of the journal; whether the manuscript is in suitable form; etc.

If this general assumption is correct, membership in a society does not carry with it an automatic right to publish in its official organ. Perhaps few think that it does, but it is a common criticism of some society research journals that editorial boards are reluctant to reject manuscripts from members, especially if these conform to the more routine requirements. This tendency is sometimes emphasized in contrasting American society journals with continental publications controlled by commercial publishers, who engage editors, usually for a consideration, who under these conditions feel no such inhibitions.

This is not the place to discuss the merits of these two systems. But it would appear that editorial boards of society research journals which feel this embarrassment may not be maintaining an altogether balanced perspective with respect to the other major elements in their responsibility, namely, that to the science and to the membership at large in limiting acceptances to what in their best judgment appear to be contributions meriting publication; and a similar responsibility, again largely to the same membership, in most wisely expending the always limited and inadequate funds contributed through subscriptions and other channels.

Though the problems are many, complicated, and difficult, it is encouraging that such organizations as the American Mathematical Society, the American Physical Society, the General Education Board, the National Academy of Sciences, the National Research Council, and others have in recent years given more or less attention to various aspects of publication. It is to be hoped that such efforts will eventually result in a thorough study of all phases. And if the results become widely available in readily understandable and correlated form, they will contribute substantially to a better adjustment of publication to research needs. Finally, it must not be overlooked that inventive genius is at work, and that revolutionary changes in the art of printing (*e.g.*, the possible use of the photoelectric cell in mechanical type-setting) may come at any time and help solve the present problems of scientific publication.

A PROVISIONAL HYPOTHESIS OF CHILD DEVELOPMENT

CHAS. B. DAVENPORT

In the course of development the child passes through a most remarkable series of changes in form and function. In the course of some 40 weeks it is transformed, by a long series of changes, from a minute spherical egg to an infant capable of complicated and useful movements and endowed with the capacity for further growth. Our problem is: What controls this series of orderly changes? Let us look at some of these changes (Fig. 1). At an early stage the embryo is almost like a segmented worm, then later the head end grows faster than the tail end. "Gill bars" appear on the neck corresponding to those of fishes. There is a long tail which gradually becomes relatively smaller. Its fore limbs, which develop in the beginning faster than the hind limbs, are at first paddle-like as in fishes, later become segmented.

This resemblance of the early stages of the child to the early stages in phylogeny has often been remarked upon. It is misleading to think of the child as passing through stages represented by the fishes, amphibia, reptiles of today, but rather we should think of it as passing in development along the same way that its ancestors did, as indicated by the black line of Fig. 2. It has gill bars because these arose in its phylogeny and have been retained in ontogeny long enough to permit the building up of blood vessels of the neck, the hyoid (or tongue) bone, the thyroid glands and a dozen other organs which are made out of those gill bars before they disappear altogether.

Again, our problem is: What is the mechanism by which the child is built up as it travels along this old path which its ancestors trod?

First, the relatively huge egg and the minute sperm must
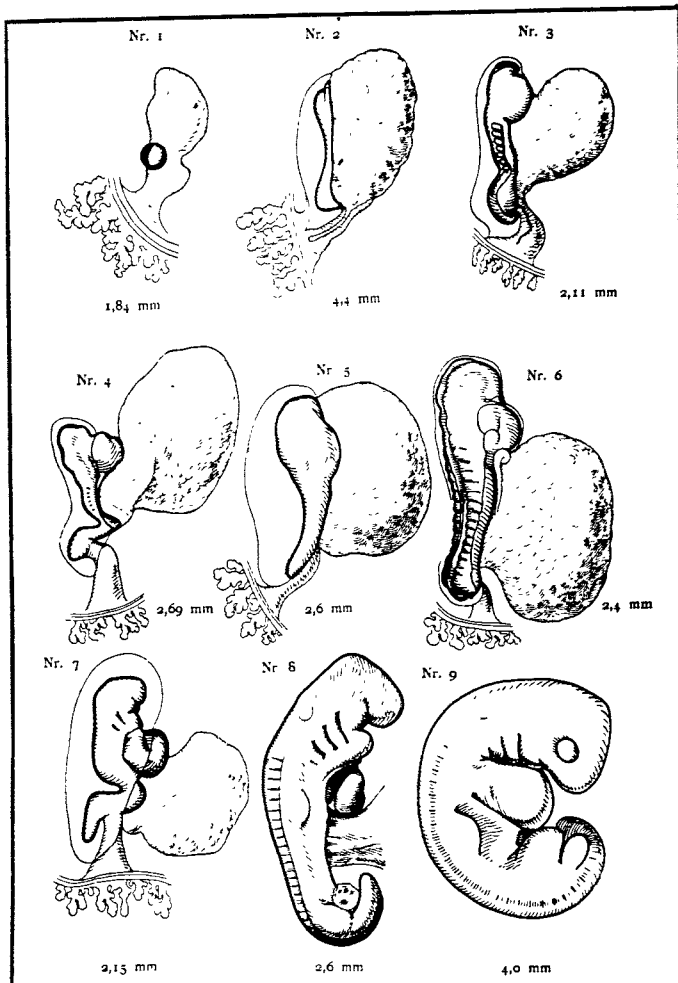
FIG. 1. Summary of the early developmental stages of the human embryo, after Kollmann. 1, The egg is attached to the maternal tissues; 2, the embryonic child is elongating; 3, muscle masses begin to show as a series of compressed spheres on each side; 4, stage with temporary kink; 5, the kink is straightened out, the head is enlarged; 6, segmentation of the trunk appears; 7, 8, 9, the embryo with gill-slits and the beginnings of the formation of appendages.

unite to insure this development. In both egg and sperm there are two groups of substances. One group is contained in a special body called the "nucleus." This nucleus constitutes practically the whole of the head of the sperm. In
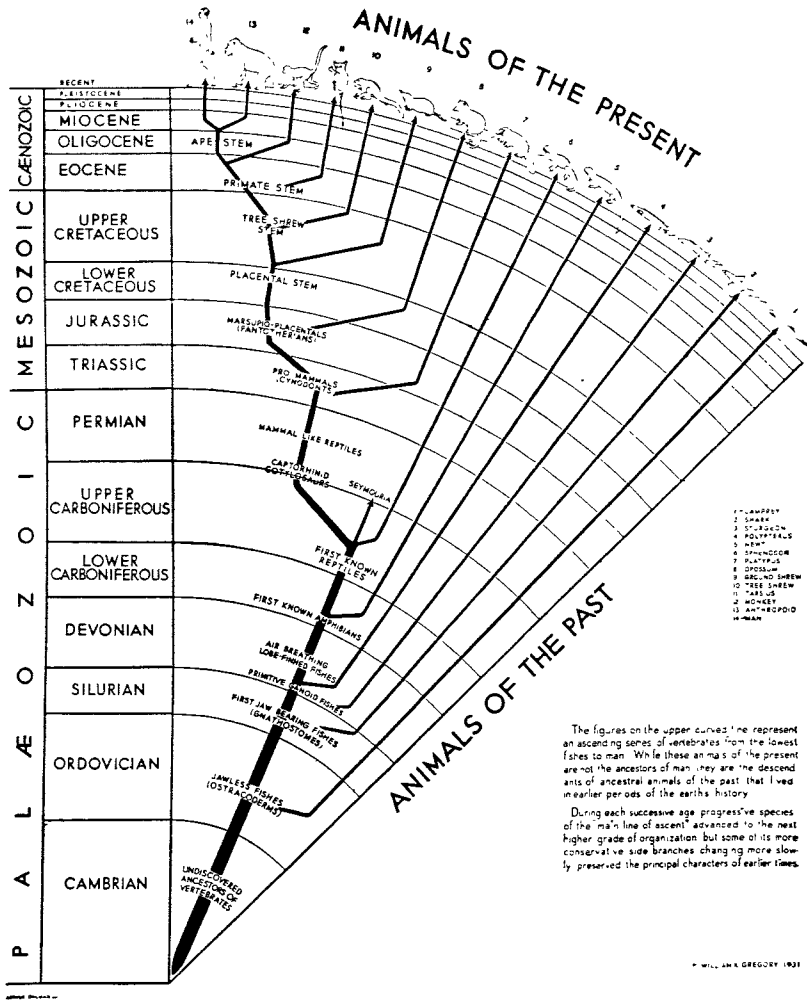
FIG. 2. Phylogenetic tree of man's evolutionary history, by Wm. K. Gregory, courtesy of the American Museum of Natural History, New York.

the egg it has about the same solids as in the sperm and compared with the rest of the egg it is a small body. The rest of the egg cell, outside of the nucleus, is called the "cytoplasm." In the sperm cell the cytoplasm is a delicate thread or tail of which little enters the egg, whereas in the egg the cytoplasm is several hundred times as massive as the nucleus.

Obviously, the cytoplasm of the egg affords the principal building material for the child's body. The cytoplasm of the egg (Fig. 3) consists of many kinds of substances. In the human egg. at which you were just looking, there is no obvious ar-
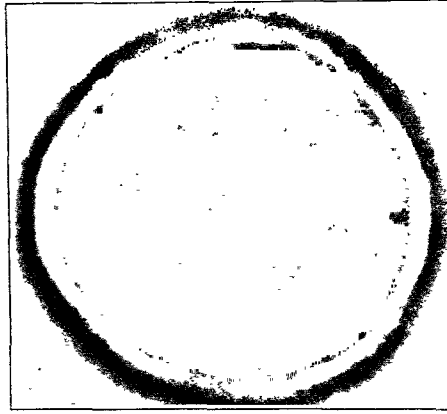
FIG. 3. A human egg, focused just beneath the surface, showing the yellow yolk granules about in focus and the mosaic of white yolk spheres (W. H. Lewis, 1931).
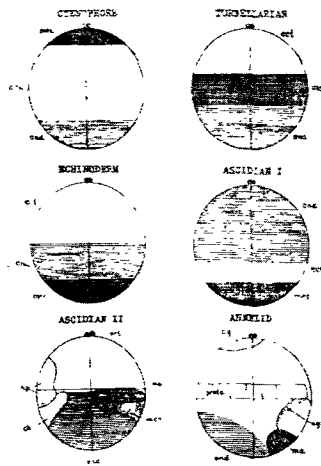
FIG. 4. Types of egg organization in different animal phyla. Cross hatched area mesoderm or mesenchyme (mes); horizontal lines endoderm (end); unshaded area ectoderm (ect). In the first four figures the pattern of localization is that found about the time of the first cleavage; in the last two figures the pattern is that found at a later stage; n.p , neural plate; ch., chorda; e.g., cerebral ganglion; v.g., ventral ganglion; proto., prototroch (E. G. Conklin, 1914).

rangement of these materials, but in many of the lower
organisms (as Conklin especially has shown) there is an organi-
zation of the different materials into different strata (Fig. 4).
We may infer that something of the same thing is true in the
human egg.   But the substances in the different strata of
the egg are of themselves insufficiently active to bring about
the metabolic changes required for the building of the cell in

FIG. 5.   Compound chromosomes of a fly.   The bands indicate the position of
the "genes" duplicated several times to form the cross band × 1500.   Courtesy of
C. W. Metz.

the hour or two available between cell divisions in the early stages of the development, or for the production of formed substance during the longer period available in later stages, or the production of particular secretions that are elaborated and periodically renewed in the cell for the general purposes of the body.

In the nucleus there are minute particles which are commonly called "genes" which are known to play specific roles in differentiation and are able to act as organic catalysts (that is, "enzymes") to accelerate metabolism.

Of these catalysts in the cell there are hundreds, if not thousands, of kinds and there is reason for thinking that each of them is essential to cell life and cell reproduction. In order to insure that the complete complement or quota of genes get into every cell at cell division the genes are arranged in linear series in a thread, so-called "chromonema," in which the genes become doubled and then the chromonemata split in two, one half going to each of the daughter cells. During this process the chromonemata are usually coiled up in what are called "chromosomes," or colored bodies.

The enzymes are so precious for the cells that in every cell division the full quota is carried over into each daughter cell. One is reminded of the way in which certain ants that raise a food fungus upon leaves find it necessary, when they start to build a new home, to carry with them some of the threads of this delicate fungus in order to continue it in the new colony. The genes are extremely small objects and can not ordinarily be seen in the chromonemata. There are, however, some compound chromonemata which show transverse bands, each one of which is believed to represent, in locus at least, a gene which has been multiplied several times transversely, so as to form the band across the compound chromosome (Fig. 5).

In the lower organisms, e.g., Amœba, where the number of genes is probably very much less than in man (just because the number of organs to be built is very much less) the necessity for precise division of each gene appears not to be present; no chromonemata are formed, but the little particles

which we assume represent genes are assembled in orderly array at the equator of the dividing cell and approximately one-half go to one daughter cell and half to the other (Fig. 6).

Our problem now is: What is the relation between the genes and the cytoplasm in the development of the child? In the resting cells the genes are all located in the nucleus. The
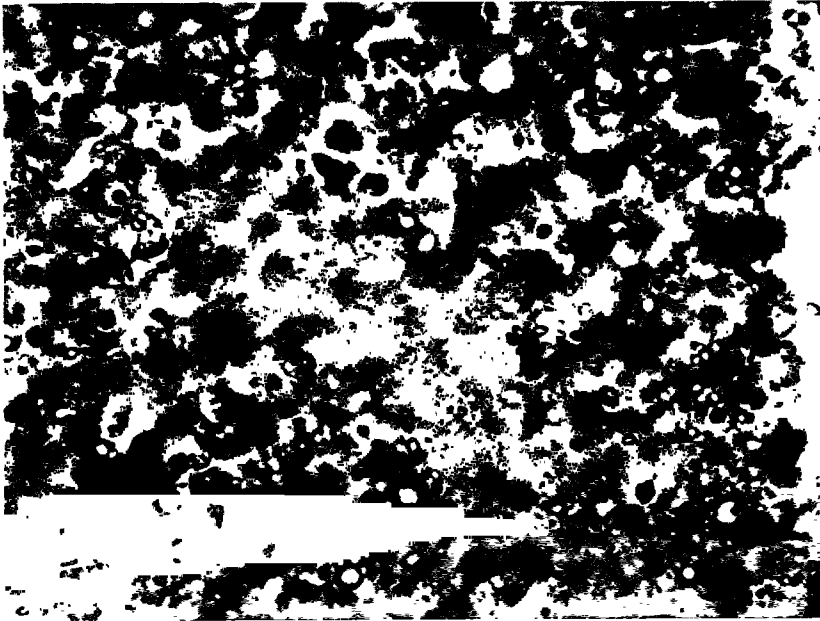
FIG. 6.   Photograph of a band or "plate" of "genes" in an Amœba that is about to divide.   Here are no true chromosomes.   Courtesy of H. W. Chalkley, photo taken by W. R. Earle.

cytoplasm in the cell is usually crowded around the "resting" nucleus. Evidently here at the wall of the nucleus is a center of great metabolic activity. This is shown very well in cells which are actively secreting, as in the case of the cells of the pancreas (Fig. 7). The nucleus is seen to be located in the midst of a dense cytoplasm, while the products of the metabolism are accumulated in the outer end of the cell, where they may empty into the duct and be carried to the alimentary tract. A similar condition is found in the

cells of the salivary glands. The nucleus lies in the region of great metabolic activity in the base of the cell; the rest of the cell is used for storage.

During this period of great activity of the nucleus where are the genes located? There is reason for thinking that the genes are usually located at the membrane separating the nucleus from the cytoplasm. This location of the genes (or their representatives) in the nuclear membrane, is well shown in many nascent sperm cells (Fig. 8).

The relation between the genes and the cytoplasm and the way in which they interact to build up the cell may be indicated hypothetically by Fig. 9. Here we have located, at the nuclear membrane, five genes. These are all different kinds of molecules, and hence have different shapes. They have, we may assume, all a negative charge. Under these circumstances any molecules in the cytoplasm which have a positive charge will be attracted toward the particles in the membrane, but they can successfully connect with them only when they have a particular molecular structure, that is, a particular shape which will enable them to interlock with the complicated shape of the gene. If interlocking is successful then the combination may, it is assumed, acquire a lessened negative charge. This reduced negative charge may, however, be sufficient to attract a second kind of molecule which will interlock with the first. Thus two molecules are brought together, their charges are neutralized and the neutral compound molecule is now separated from the gene and passes over to do its specific work in the cell—perhaps to build a cell wall, perhaps to build up a particular excretion or hormone, perhaps to lie latent until in some later cell stage it has an opportunity to unite with still other genes of the nuclear membrane. When the gene of the nuclear membrane, which we have been considering, has thus discharged the pair of molecules which it has united, it becomes available for the same process again, and thus there are produced a vast number of similar molecules through the activity of the gene. This process really goes on at a tremendously rapid rate,
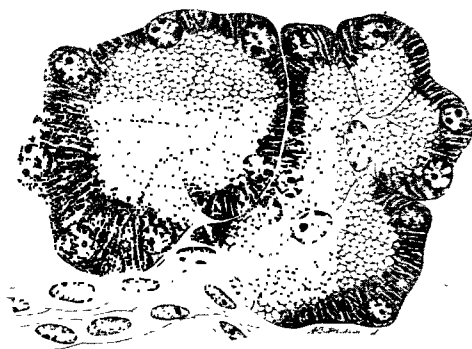
FIG. 7.   Cells of the pancreas of the guinea pig, showing little spheres of secretion about to be passed out into the duct, seen below and to left × 1555.   After Bensley from Maximow-Bloom Histology, W. B. Saunders Company, publishers.
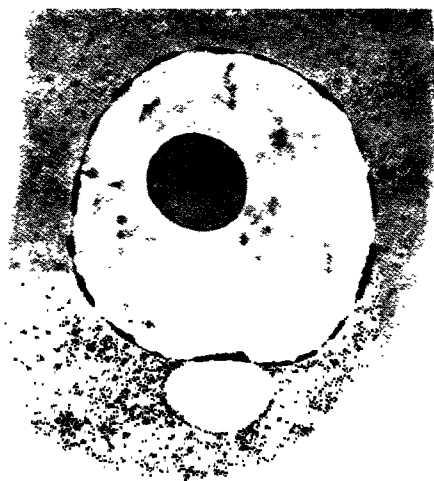
FIG. 8.   "Spermatocyte" in the formation of the sperm cell of a spider, showing staining substance (probably representing genes) at the nuclear membrane (the large circle surrounding the light area with a very dark central body).   From Sokolow.

hundreds or thousands of molecules being united in a single second.   A substance which accelerates the union of molecules in this fashion is known as an enzyme, and we think of the genes as enzymes acting to produce, with enormous rapidity, the required substances in each cell.

Through the kindness of Professor J. A. Northrop I am

able to show you some crystals of substances which are pro-
duced by cell activity, no doubt by the activity of the genes.
On the left are seen crystals of a substance called "trypsino-
gen." It is formed in the cells of the pancreas. It is chemi-
cally *inactive*. By further chemical change, expedited by an
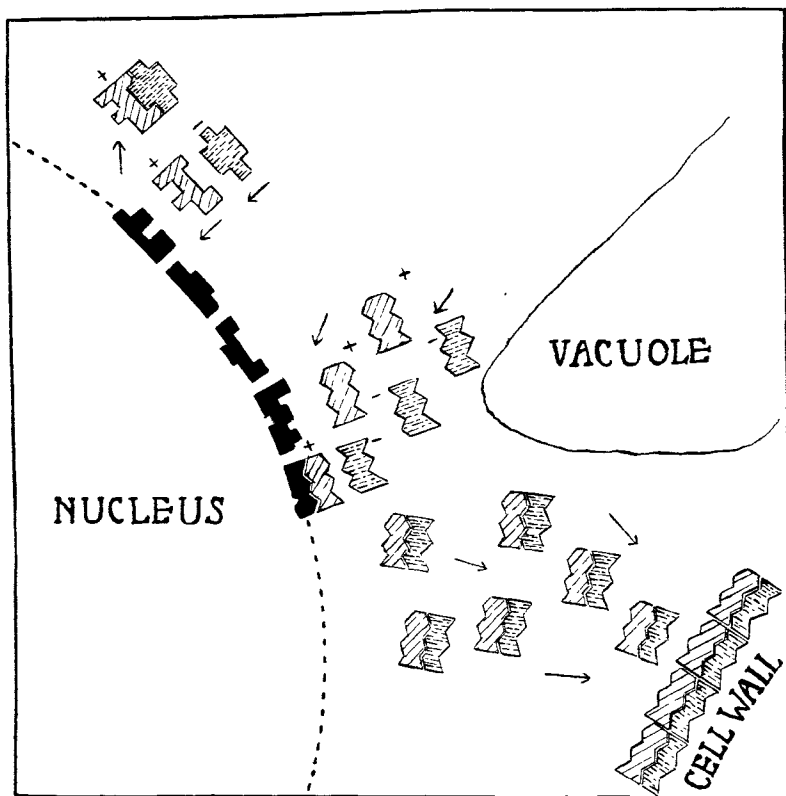
FIG. 9. Hypothetical machinery at the nuclear membrane for the formation of
specific molecules by enzyme action.

enzyme, it is transformed into "trypsin," a very active sub-
stance, secreted by the pancreas. The enzyme that is respon-
sible for the quick transformation is called "enterokinase"
(Fig. 10).

In any cell, at a given time, those genes can act which
find fitting molecules in the cytoplasm upon which to act.
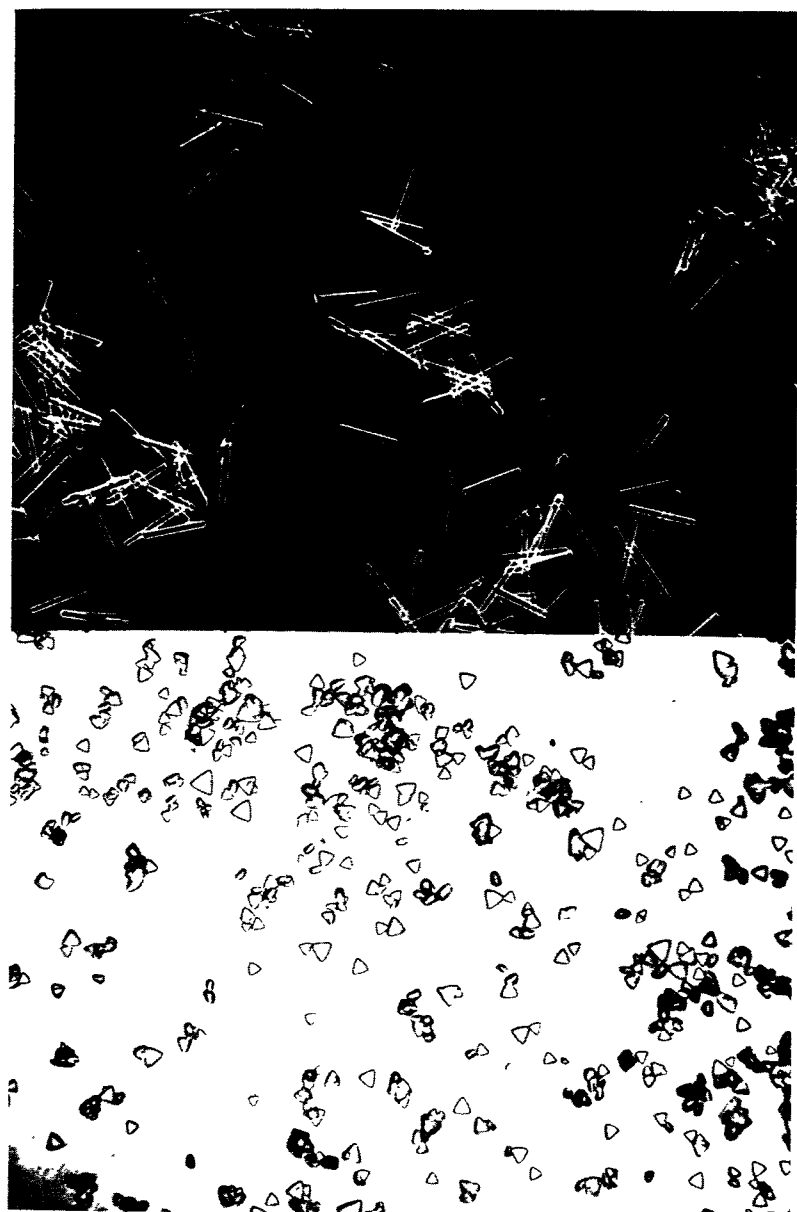
Fig. 10. At the left, crystals of trypsinogen in inactive substance which under the influence of an enzyme (enterokinase) becomes transformed into the very active substance, crystals of which are shown at right—trypsin. Courtesy of Dr. J. A. Northrop.

The genes can now only *accelerate* chemical unions which are already set to take place and which might conceivably eventually occur without the genes. Unless there is an appropriate molecular set-up in the cytoplasm any particular gene can not act in the cell, but will lie fallow until in some later cell generation there have been produced molecules the chemical operation of which it is believed to activate. Thus it comes about that during development only one set of chemical processes can take place at one time, and those that take place in the immediately following time depend upon the molecules that have already been produced. Thus it comes about that the genes are able to do their work at the appropriate time and place, and thus the organism is built up in orderly fashion.

SOME TWO-DIMENSIONAL DISTRIBUTIONS OF ELECTRICITY

E. P. ADAMS

1. The number of exact solutions that have been obtained for the problem of the distribution of electricity on conductors is small. One problem that requires the use of elementary functions only is that of an infinitely long cylinder the cross-section of which is any sector of a circle. In order to solve this problem we shall use the method of conformal transformation described in a previous paper [1] and applied to two infinitely long circular cylinders.

2. Let a be the radius of the sector and 2α its angle at the center of the circle of which it forms a part. Take the origin of coördinates in the z-plane at o, the center of the circle, and the x-axis passing through the center of the circular arc. The upper half of the z-plane, which, on account of symmetry, is all that we need to consider, is shown in Fig. 1.
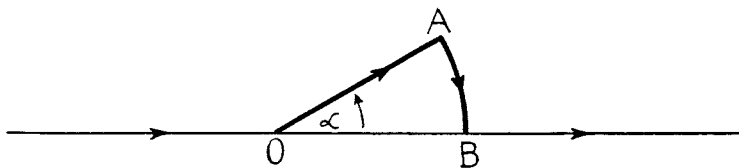
FIG. 1.

The transformation

$$w = \log z/c, \tag{1}$$

where $w = u + iv$, gives

$$u = \log r/c, \qquad v = \theta,$$

where r and θ are the polar coördinates of any point in the plane. Along the x-axis, from $-\infty$ to o, $v = \pi$, and u decreases from $+\infty$ to $-\infty$. Along the radius OA, u increases

[1] *Proceedings American Philosophical Society*, No. 1, Vol. LXXV.

from $-\infty$ to $\log a_i'c$, and $v = \alpha$. Along the circular arc AB, $u = \log a/c$ and v decreases from α to 0. Finally, along the x-axis from B to ∞, u increases from $\log a'c$ to ∞, and $v = 0$. The w-plane is represented in Fig. 2, and is to be transformed
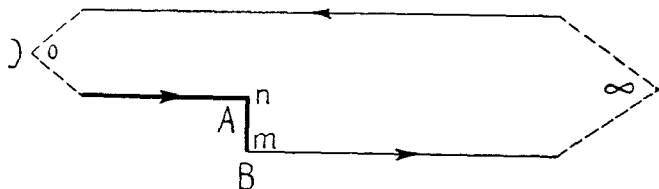
FIG. 2.

to the upper half of the t-plane so that the boundary of the w-plane becomes the real axis of the t-plane; points inside the boundary of the w-plane transform to the upper half of the t-plane. If we choose the real quantities m and n, the values of t that correspond to A and B, with

$$\infty > m > n > 0 > -\infty,$$

the Schwarz-Christoffel transformation gives the following differential equation for effecting this transformation:

$$\frac{dw}{dt} = A\frac{(t-n)^{1/2}}{t(t-m)^{1/2}}. \tag{2}$$

We can choose one relation between m and n; it will be found convenient to take

$$mn = 1. \tag{3}$$

In going from $t = +\infty$ to $t = -\infty$ along a semi-circle of infinite radius, w increases by $i\pi$. By integration along this semi-circle we get $A = 1$. In passing along a semi-circle of infinitely small radius at $t = 0$, from left to right along the real t-axis, w decreases by $i(\pi - \alpha)$; so by integration we get

$$\left(\frac{m}{n}\right)^{1/2} = m = \frac{\pi}{\pi - \alpha}. \tag{4}$$

The integral of (2) will be expressed in three forms, cor-

responding to the three ranges of t: (1) $\infty > t > m$, (2) $m > t > n$, and (3) $n > t > 0$. If these three integrals be denoted by w_1, w_2 and w_3, we have

$$\frac{w_1}{2} - \frac{1}{2}\log\frac{a}{c} = \sinh^{-1}\left\{\frac{m(t-m)}{m^2-1}\right\}^{1/2}$$
$$- \frac{1}{m}\sinh^{-1}\left\{\frac{t-m}{t(m^2-1)}\right\}^{1/2}, \quad (5)$$

$$\frac{w_2}{2} - \frac{1}{2}\log\frac{a}{c} = i\sin^{-1}\left\{\frac{m(m-t)}{m^2-1}\right\}^{1/2}$$
$$- \frac{i}{m}\sin^{-1}\left\{\frac{m-t}{t(m^2-1)}\right\}^{1/2}, \quad (6)$$

$$\frac{w_3}{2} - \frac{1}{2}\log\frac{a}{c} - i\frac{\alpha}{2} = \sinh^{-1}\left\{\frac{1-mt}{m^2-1}\right\}^{1/2}$$
$$- \frac{1}{m}\sinh^{-1}\left\{\frac{m(1-mt)}{t(m^2-1)}\right\}^{1/2}. \quad (7)$$

These integrals satisfy the conditions,

$$t = m, \qquad w_1 = w_2 = \log a/c,$$
$$t = n, \qquad w_2 = w_3 = \log a/c + i\alpha.$$

3. We shall need the relation between z and t when both these variables approach infinity. The inverse hyperbolic functions in (5) may be expressed in terms of logarithmic functions; when this is done and we take the limiting values for large t, we find

$$\underset{t\to\infty}{\text{Limit}}\frac{t}{z} = \left(\frac{m+1}{m-1}\right)^{i/m}\frac{m^2-1}{4ma}. \quad (8)$$

We shall also need the relation between r and t on the radius OA. Since

$$w_3 = \log r/c + i\alpha$$

on this radius, we get from (7) by turning to logarithms,

$$\frac{r}{a} = \frac{\{t(m^2-1)\}^{1/m}}{m^2-1}$$
$$\times \frac{1+m^2-2mt+2\{m(1-mt)(m-t)\}^{1/2}}{[2m-m^2t-t+2\{m(1-mt)(m-t)\}^{1/2}]^{1/m}}. \quad (9)$$

When t and r approach zero, near the origin o, we get

$$\underset{t \to 0}{\text{Limit}} \frac{t^{1/m}}{r} = \frac{1}{a}(m^2 - 1)^{(m-1)/m} \frac{(4m)^{1/m}}{(m+1)^2}. \tag{10}$$

On the circular arc,

$$w_2 = \log a'c + i\theta,$$

and we get from (6)

$$\frac{1}{2}\theta = \sin^{-1}\left\{\frac{m(m-t)}{m^2-1}\right\}^{1/2} - \frac{1}{m}\sin^{-1}\left\{\frac{m-t}{t(m^2-1)}\right\}^{1/2}. \tag{11}$$

4. We shall first suppose the cylinder to be freely charged, with Q as the charge on unit length. Referring to Fig. 1, we see that the x-axis from $-\infty$ to o is a line of force; we shall take this to be $\psi = $ o. If we take $\phi = $ o as the potential of the cylinder, ϕ will increase from $-\infty$ to o along the x-axis from $-\infty$ to o. Along OAB, $\varphi = $ o, and ψ increases from o at O to $2\pi Q$ at B. The x-axis from B to $+\infty$ is also a line of force; along it $\psi = 2\pi Q$ and φ decreases from o to $-\infty$. The χ-plane, where $\chi = \varphi + i\psi$, is represented in Fig. 3, and
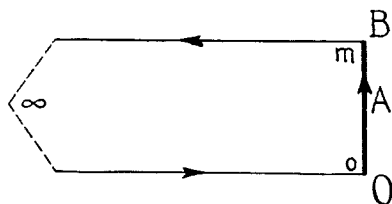
Fig. 3.

its transformation to the t-plane is given by

$$\frac{d\chi}{dt} = \frac{C}{\{t(t-m)\}^{1/2}}. \tag{12}$$

Since χ decreases by $2\pi iQ$ when t describes a semi-circle of infinite radius from $t = +\infty$ to $t = -\infty$, we get by integration

$$C = -2Q.$$

The integral of (12) that satisfies the conditions,

$$t = 0, \qquad \chi = 0,$$
$$t = m, \qquad \chi = 2\pi iQ,$$

is

$$\chi = - 4iQ \sin^{-1} \left\{ \frac{m - t}{m} \right\}^{1/2} + 2\pi iQ. \tag{13}$$

From this we get the value of ψ at A, where $t = 1/m$,

$$\psi = 2\pi Q - 4Q \sin^{-1} \left(\frac{m^2 - 1}{m^2} \right)^{1/2}.$$

The charge on unit length of the curved portion of the cylinder, Q_1, is given by the relation,

$$2\pi Q_1 = \psi(t = m) - \psi(t = 1/m),$$

and the charge on unit length of the plane portions of the cylinder Q_2, by

$$2\pi Q_2 = \psi(t = 1/m) - \psi(t = 0).$$

So we get

$$Q_1 = \frac{2Q}{\pi} \sin^{-1} \left(\frac{m^2 - 1}{m^2} \right)^{1/2},$$

$$Q_2 = Q - Q_1.$$

For a semi-circular cylinder, with $\alpha = \pi/2$, $m = 2$, we find that two-thirds of the whole charge is distributed over the curved portion of the cylinder and one-third over the base.

The surface density, σ, of the charge on the conductor is given by

$$4\pi\sigma = \left| \frac{d\chi}{dz} \right|. \tag{14}$$

Now

$$\frac{d\chi}{dz} = \frac{d\chi}{dt} \frac{dt}{dw} \frac{dw}{dz}, \tag{15}$$

and so by (12), (2), and (1), we have

$$\frac{d\chi}{dz} = - \frac{2Q}{z} \left\{ \frac{mt}{mt - 1} \right\}^{1/2}.$$

From this we find the surface density on the curved portion of
the cylinder to be given by

$$\sigma_1 = \frac{Q}{2\pi a}\left(\frac{mt}{mt - 1}\right)^{1/2}. \tag{16}$$

The values of t in the range $1/m \leqslant t \leqslant m$, corresponding to
any values of θ in the range $0 \leqslant \theta \leqslant \alpha$, are given by (11).

The surface density on the plane portions of the cylinder
is given by

$$\sigma_2 = \frac{Q}{2\pi r}\left(\frac{mt}{1 - mt}\right)^{1/2}, \tag{17}$$

where r is the distance of the given point from the centre, O,
of the circle. In this case t lies in the range $0 \leqslant t \leqslant 1/m$, and
corresponding values of t and r are given by (9). At the
point o itself, where $t = 0$ and $r = 0$, we must evaluate
$t^{1/m}/r$. We find from (10) that if $\alpha = \pi/2$, the surface density
at o is finite; it is zero if α is greater than $\pi/2$, but is infinite
if α is less than $\pi/2$. The surface density is infinite at A,
where $t = 1/m$, in every case.

5. For a semi-circular cylinder, with $m = 2$, equation (11)
reduces to

$$\cos \theta = \left\{\frac{2}{27}\left(\frac{2t - 1}{t}\right)\right\}^{1/2}(2t - 1). \tag{18}$$

The distribution of the charge on a semi-circular cylinder is
shown in Figs. 4 and 5. Figure 4 is plotted from (17) and (9);
the abscissae are r, ranging from 0 to 1, and the ordinates are
$2\pi\sigma a/Q$. Figure 5 is plotted from (16) and (18); the abscissæ
are θ, ranging from 0 to $\pi/2$ and the ordinates are the same
as in Fig. 4.

6. We shall now determine the distribution of the induced
charge on the cylinder when it is placed in a uniform electric
field, taking first the case when the field is along the x-axis.
The potential of the external field may be taken as Fx. The
x-plane for the uncharged cylinder is shown in Fig. 6. The
whole x-axis outside the cylinder is a line of force, the potential
increasing from $-\infty$ to $+\infty$ along it. The point S sepa-
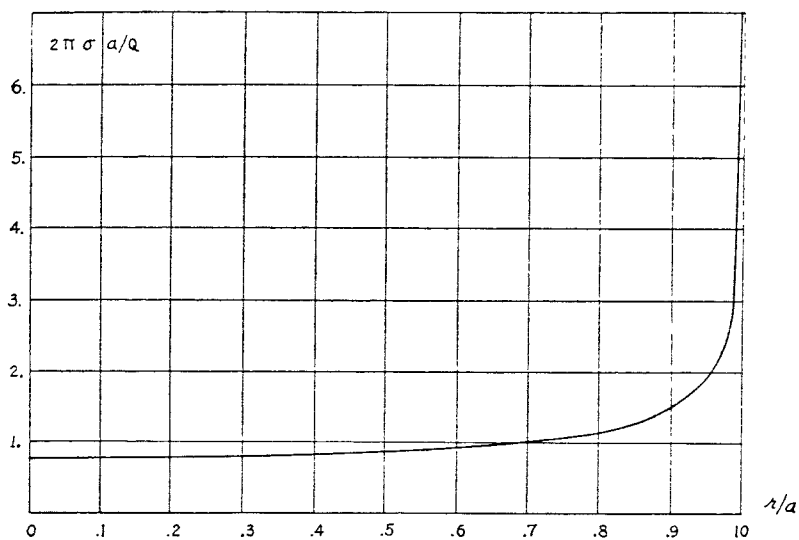
FIG. 4.
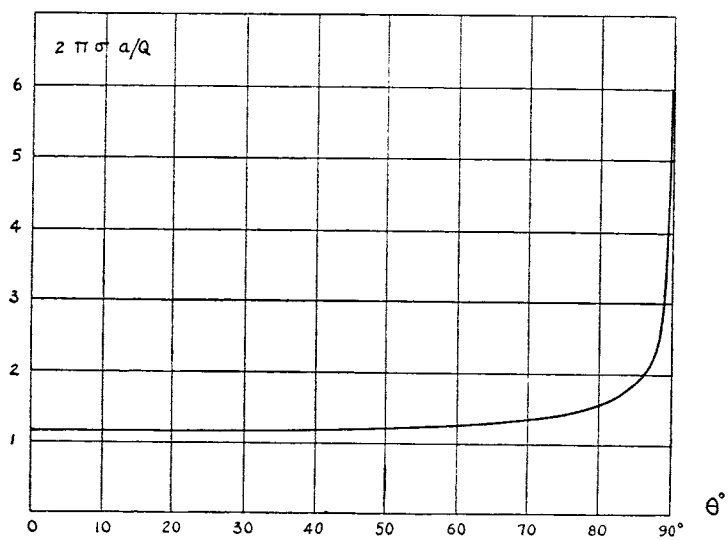
FIG. 5.
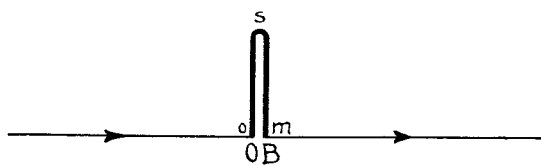
FIG. 6.

rates the negative induced charge to the right from the positive induced charge to the left. We shall take $t = s$ as the real value of t corresponding to this point. Then the transformation to the t-plane gives

$$\frac{d\chi}{dt} = \frac{C(t - s)}{\{t(t - m)\}^{1/2}}. \tag{19}$$

The integral of (19) may be written in either of the forms

$$\chi_1 = C\{t(t - m)\}^{1/2}, \qquad t > m, \tag{20}$$
$$\chi_2 = iC\{t(m - t)\}^{1/2}, \qquad t < m. \tag{21}$$

In order to satisfy the conditions

$$\chi_1 = \chi_2 = 0 \quad \text{when} \quad t = m$$

and

$$\chi_2 = 0 \quad \text{when} \quad t = 0,$$

we must have

$$s = m/2. \tag{22}$$

This determines the position of the point of equilibrium. When t approaches infinity, (20) gives

$$\chi_1 = Ct,$$

and as the real part of χ_1 must approach the value Fx, we get from (8),

$$C = \frac{4\pi a F}{\alpha} \left(\frac{\alpha}{2\pi - \alpha} \right)^{(\pi - \alpha)/\pi} \frac{\pi - \alpha}{2\pi - \alpha}, \tag{23}$$

where m has been expressed in terms of α by (4).

The charge induced on unit length of the curved portion of the cylinder can be found from (21) and is

$$Q_1 = -\frac{C}{2\pi^2} \{\alpha(2\pi - \alpha)\}^{1/2}.$$

There is an equal and opposite charge induced on the plane portions of the cylinder.

The point of equilibrium, S, will coincide with the edge, A, of the cylinder if $s = m/2 = 1/m$, so that $m = \sqrt{2}$. This

value of m corresponds to an angle α given by

$$\alpha_0 = \frac{\pi}{2}(2 - \sqrt{2}) = 52° 43'.$$

If α is greater than α_0 the point of equilibrium lies on the curved portion of the cylinder, and it lies on the plane portion if α is less than this value. Its position in either case can be determined from (9) or (11).

The surface density of the induced charge is found from (14) and (15), where (19) is used in the latter equation. We therefore get for the surface density on the curved portion of the cylinder

$$\sigma_1 = -\frac{C}{4\pi a}\left(t - \frac{m}{2}\right)\left(\frac{mt}{mt - 1}\right)^{1\cdot 2} \tag{24}$$

and on the plane portions of the cylinder,

$$\sigma_2 = -\frac{C}{4\pi r}\left(t - \frac{m}{2}\right)\left(\frac{mt}{1 - mt}\right)^{1/2}. \tag{25}$$

The constant C is given by (23). We must use (11) for the relation between t and θ in (24), and (9) for the relation between r and t in (25).

If the uniform electric field is along the y-axis its potential will be Fy. The χ-plane is now simply the t-plane turned through a right angle, so that we have

$$\chi = -iCt.$$

The constant C has the value given in (23), and we find the charge induced on the curved portion of the upper half of the cylinder to be

$$Q_1 = -\frac{1}{4\pi}C\frac{m^2 - 1}{m}.$$

The charge induced on the upper plane portion of the cylinder is

$$Q_2 = -\frac{1}{4\pi}\frac{C}{m}.$$

The charges induced on the lower half of the cylinder are equal and opposite to Q_1 and Q_2.

The surface density of the induced charge on the curved portion is

$$\sigma_1 = -\frac{Ct}{4\pi a}\left\{\frac{m(m-t)}{mt-1}\right\}^{1/2}. \tag{26}$$

This vanishes at $t = m$. On the plane portion the surface density is

$$\sigma_2 = -\frac{Ct}{4\pi r}\left\{\frac{m(m-t)}{1-mt}\right\}^{1/2}. \tag{27}$$

It may be shown by the use of (10) that σ_2 vanishes at $t = 0$ where $r = 0$.

By superposition of the results for fields along the x- and y-axes, the surface densities of the induced charge may be found for fields making any angle with the x-axis.

7. In his "Recent Researches in Electricity and Magnetism," Articles 245–254, Sir J. J. Thomson solves a number of problems by the indirect method of assuming certain relations, expressed in terms of elliptic functions, between the variables z and the complex potential (denoted there by w), and then determining the problem to which any given relation applies. All of these problems may readily be solved by the direct method that has been used here. In order to show the application of this method to such condenser problems, two similar problems will be solved.

Let CD and EF represent two infinite conducting plates at potential zero, and AB an infinitely long conducting strip, of finite breadth, at potential V, placed midway between the infinite plates. By symmetry, we need consider only the region enclosed within the dotted lines in Fig. 7. The x-axis
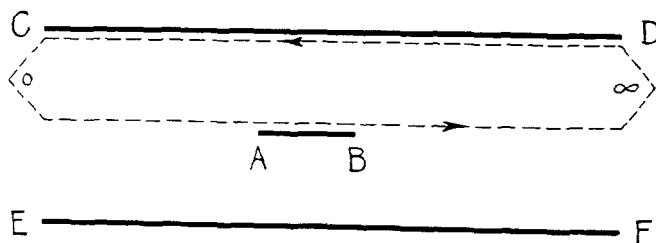
Fig. 7.

is taken as passing through AB, with the origin at A. Transforming this region to the upper half of the t-plane, we get

$$z = \frac{h}{\pi} \log t, \tag{28}$$

where $2h$ is the distance between the two infinite planes. We shall take $\psi = 0$ for the line of force CA, and $\psi = 2\pi Q$ for the line of force BD, where Q is the charge on unit length of the strip AB. The equipotential AB is $\varphi = V$, and along DC, $\varphi = 0$. The χ-plane is accordingly shown in Fig. 8. The
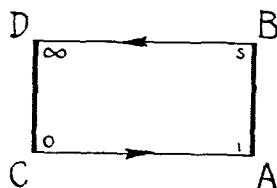
Fig. 8.

values of t at the four corners, C, A, B and D are taken as 0, 1, s and ∞. The Schwarz-Christoffel transformation gives

$$\frac{d\chi}{dt} = \frac{C}{\{t(t-1)(t-s)\}^{1/2}}. \tag{29}$$

To integrate, we put

$$t = sn^2 \lambda,$$

with the modulus, k, given by

$$k^2 = 1/s,$$

and we get

$$\chi = -2Ck\lambda + D. \tag{30}$$

Corresponding values of t, λ, and χ are given in the scheme:

$$
\begin{array}{ccccc}
t = & 0 & 1 & s = 1/k^2 & \infty, \\
\lambda = & 0 & K & K + iK' & iK', \\
\chi = & 0 & V & V + 2\pi iQ, & 2\pi iQ.
\end{array}
$$

Substitution in (30) gives

$$
\begin{aligned}
D &= 0, \\
kC &= -V/2K, \\
Q &= VK'/2\pi K.
\end{aligned} \tag{31}
$$

K and K' are the complete elliptic integrals of the first kind to the moduli k and k'. If a is the breadth of the strip, the modulus, k, is found from (28) by putting $z = a$ and $t = 1/k^2$, with the result,

$$k = e^{-\pi a/2h}.$$

Having determined k, the capacity of unit length of the condenser is

$$S_1 = \frac{K'}{2\pi K}.$$

The surface density at any point of the conductor is given by

$$4\pi\sigma = \left|\frac{d\chi}{dz}\right|.$$

Its value at a point distant x from the edge A of the strip AB is found to be

$$\sigma = \frac{V}{8Kh} \frac{e^{\pi a/2h}}{\{(e^{\pi x/h} - 1)(e^{\pi(a-x)/h} - 1)\}^{1/2}}.$$

Let, now, the two infinite plates separate to an infinite distance. Then $h = \infty$, $k = 1$, $K = \infty$, $K' = \pi/2$. V, the difference of potential between the strip and the two infinite plates, approaches infinity in such a way that, by (31),

$$V/K = 4Q.$$

On going to the limit, the surface density on the strip is given by

$$\sigma = \frac{Q}{2\pi} \frac{1}{(x(a - x))^{1/2}},$$

which is a known result for a freely charged infinite strip of breadth a, with a charge Q per unit length.

8. We next take the case when the infinite strip is placed at right angles to the two parallel infinite planes, midway between them. The z-plane is shown in Fig. 9. By symmetry, we need consider only the area inside the dotted lines. We shall take $t = 0$ at C, s at A, and 1 at O and ∞ at D.
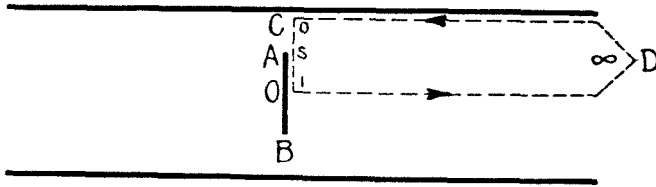
FIG. 9.

Then the transformation to the t-plane is given by

$$\frac{dz}{dt} = \frac{A}{\{t(t-1)\}^{1/2}} \cdot \tag{32}$$

Since z jumps by ih at ∞, $A = h'\pi$, and we find

$$z = \frac{2ih}{\pi} \sin^{-1}(1-t)^{1/2}.$$

When $t = s$, $z = ib$, if $2b$ is taken as the breadth of the strip. Therefore

$$s = \cos^2 \frac{\pi b}{2h}$$

and

$$t = \cos^2 \frac{\pi y}{2h} \cdot$$

This gives the value of t at any point of the strip determined by y.

The χ-plane is the same as in Fig. 8 except that s and 1 are interchanged. We find just as before

$$\chi = -2C\lambda + D,$$

with

$$t = s\, sn^2\lambda$$
$$D = 0,$$
$$C = -V/2K,$$
$$Q = VK'/\pi K.$$

The modulus, k, of the elliptic functions is given by

$$k^2 = s,$$

and so

$$k = \cos \frac{\pi b}{2h}.$$

The capacity of a unit length of the strip of breadth $2b$ is

$$S_2 = K'/\pi K.$$

We find the surface density on the strip just as in the previous case. The result is

$$\sigma = \frac{\pi Q}{8K'h} \frac{1}{\left\{ \frac{1}{2} \left(\cos \frac{\pi y}{h} - \cos \frac{\pi b}{h} \right) \right\}^{1/2}},$$

where y is measured from the centre of the strip.

When the two infinite plates separate to an infinite distance we get

$$\sigma = \frac{Q}{2\pi} \frac{1}{(b^2 - y^2)^{1/2}},$$

which agrees with the value found for the previous case when the strip was parallel to the infinite planes.

When the ratio of the breadth of the strip to the distance apart of the two parallel planes is small, the capacities of unit lengths of the two condensers are nearly equal; their difference increases as this ratio increases. The capacity S_2 when the strip is perpendicular to the planes is always greater than the capacity S_1 when it is parallel to the planes. For example, for

$$b/h = a/2h = 1/2,$$
$$S_1 = 0.2985,$$
$$S_2 = 0.3183.$$

While for

$$b/h = a/2h = 3/4,$$
$$S_1 = 0.3778,$$
$$S_2 = 0.4677.$$

9. The problem of the distribution of electricity on a freely charged cylindrical shell, that is, an infinitely long

cylinder the cross section of which is a circular arc, was solved by Bickley.[2] All of his results may be obtained rather more easily by the method used in this paper; the transformation (1) is required. The components of force and the couple acting on the shell in a continuous flow of fluid may also be obtained; the latter problem requires the same analysis as that of finding the distribution of induced charges on the conductor when it is placed in a uniform electric field.

Another problem that can readily be solved by this method is that of the distribution of electricity on two infinitely long strips of equal breadths meeting at any angle. The more general problem of strips of unequal breadths was solved by Morton.[3] On account of the lack of symmetry when the breadths are not equal the method here used is not applicable.

[2] *Phil. Mag.*, 35, 1918, p. 396.

[3] *Phil. Mag.*, 1, 1926, p. 337; 2, 1926, p. 900.

TERTIARY PLANTS FROM BRAZIL

EDWARD W. BERRY

THE ONLY post-Paleozoic fossil plants from the over three and a quarter million square miles constituting the Republic of Brazil that have ever been described in print are several collections made at different times by different persons and brought together in a paper by Hollick and Berry [1] published in 1924. These were all from the State of Bahia and within 100 miles of its capital, São Salvador and have been determined as of Pliocene age.

In such a vast region where comparable fossil floras are unknown nearer than the Andean region, and there only to a very limited extent, direct comparison of fossil forms is impossible. Much reliance was placed on the close resemblance of the fossil flora from Bahia to the recent flora of tropical South America, but in Equatorial regions except where there has been great orogeny, as in the Andean region, it is difficult to evaluate the effects of mere lapse of time. Finally an effort was made to fit the fossil flora into the geologists' picture of the physiographic history of the region. The conclusion from these various lines of inquiry was, as stated above, that the age was Pliocene, but whether early or late in that epoch it was impossible to surmise.

The collections upon which the present study is based were transmitted to me in 1929 from the Geological Survey of Brazil through David White, and obviously represent material which had accumulated in the Museum at Rio de Janeiro. For example, Nos. 1442 to 1446 were collected by Roderic Crandall, who I happen to know was John C. Branner's assistant, and this collection was made in 1907. Those from the other localities are as old or probably older, since the only

[1] Hollick, A. & Berry, E. W. Johns Hopkins University Studies in Geology No. 5, 136 pp., 13 pls., 1924.

Brazilian document in which I can find any mention of them
was Gorceix's paper, published in 1884.

Three localities are mentioned on the labels; they are
Mocambo, Marahú and Fonseca. The first two are in the
State of Bahia and the third is in the State of Minas Geraes.

The material from Mocambo (Nos. 1442–1446) made by
Crandall in 1907 has a matrix which is a banded yellowish and
pinkish, soft, soapy clay uncovered in grading the right of way
for the Bahia a São Francisco Railway in the 1870's and is
identical with the collection preserved at the Rensselear
Polytechnic Institute to which it was presented by the late
Miguel de T. Argollo of Bahia in 1871, with the collection
made by G. A. Waring in 1903 and by Branner and Crandall
in 1907 and now at the N. Y. Botanical Garden, and probably
with the collection made by Eugen Hussak which was sent
to Ettingshausen at Gratz (before 1897) [1] and with the one sent
by Orville A. Derby to the Museum d'Histoire Naturelle at
Paris and commented on by Bonnet [2] in 1905.

It is thus certain that Mocambo is the same or a nearby
locality as what Krasser called Ouricanga and what Hollick
and Berry called Aramary—the latter being the nearest town
—the actual outcrop being 14.7 km. north of Aramary station
and in a practically uninhabited region.

The plants from Mocambo contained in the present collec-
tion are the following:

       1442. *Canella winterianafolia* Hollick and Berry
       1443. *Rheedia pliocenica* Hollick and Berry
       1444. *Couroupita ovata* Hollick and Berry
       1445. *Coccolobis preuvifera,* new
       1446. *Leptolobium eonitens* Hollick and Berry

As may be noted the plant species confirm the lithology since 4
of the 5 are forms which were described from Aramary.

The other locality in Bahia—Marahú—is what was called

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[1] Krasser, F. Konstanten von Ettingshausen's Studien über die fossile Flora von
Ouricanga in Brasilien. K akad Wiss wien mathnat. K. Sitz. Bd. 112, pp. 852–860, 1903.

[2] Bonnet, F. Contribution à la flore pliocène de la province de Bahia (Brésil),
Mus d'Hist. Nat. Bull. t. 11, pp. 510–512, 1905.

by Hollick and Berry, Marahii. The present collection con-
sists of but 5 specimens and shows two lithologies. The
specimens 1459 and 1460 are grayish to brownish in color and
so light in weight that I examined them for diatoms without
success. Under the impression that the material might be a
volcanic ash I sent a sample to C. P. Ross who was good
enough to examine it for me. He reports as follows:

"It is composed of an isotropic clay material containing a large
proportion of carbonaceous material, inclosing a small proportion
of detrital quartz grains. The index of refraction of the clay and
the isotropic character indicate that it is halloysite."

The other three specimens from this locality (Nos. 1557–
1559) are heavier and a hard grayish brown laminated clay,
with laminæ upwards of ¼ inch thick, separated by films with
leaf impressions, plant fragments, and angular quartz sand
grains.

The identifications from Marahú are the following:

1459. *Simaruba whitei* Hollick and Berry
1460. *Calyptranthes marahiensis* Hollick and Berry
1557. *Heliconia bahiana*, new
1558. *Myrcia rostrataformis* Hollick and Berry
1559. *Calyptranthes marahiensis* Hollick and Berry
and *Cassia marahiana* Hollick and Berry, which was
worked out of specimen 1460.

Except for the new *Heliconia*, all are previously known forms
from the Bahia Pliocene.

The third locality is Fonseca in the southeastern part of the
State of Minas Geraes. This is in the district of Ouro Preto
and is about 31 km. east of north of the town of that name at
the base of the Serra do Caraca (Lat. circa 20° South, Longi-
tude circa 43° 30′ west). Plant bearing Tertiary deposits
have been known from here for a long time and from a second
locality known as Gandarela northwest of Fonseca. These
were described by Gorceix[1] in 1884. All of the plants sub-

[1] Gorceix, H. Bacias terciarias d'agua doca nos Arredores de Ouro Preto (Ganda-
rela e Fonseca). Annaes da Escola de Minas, No. 3, pp. 95–114, Rio de Janiero, 1884.

mitted to me are from Fonseca, and I know nothing of the other locality beyond the statement of Gorceix that Melastomaceæ are rare and that there are numerous Leguminosæ, Lauraceæ, Rubiaceæ, Sapindaceæ and Ficus. It seems quite evident from the material that I have seen from Fonseca that it is nothing more than a sample and that intensive collecting would disclose a large and well preserved flora.

The matrix of the Fonseca plants is a dark gray, hard, laminated clay sometimes weathered to a light brown, with films of light and rather coarse sand with quartz feldspar and mica. The sand partings contain much comminuted vegetable matter which is also disseminated in the clay, and leaf impressions.

The minerals of the sand partings obviously represent flood water sediment from areas of granitic rock. Whether this was carried into a lake basin or spread over a river flood-plain I have no means of knowing. The deposits are spoken of by Gorceix and referred to by Branner and others as "Lake deposits." I understand that some layers are lignitic and attempts have been made to utilize them commercially, especially in the Gandarela Basin.

Gorceix's graphic section of the Fonseca outcrop is reproduced herewith (Text Fig. 1). Whether this is drawn to scale

Ferruginous cemented
rubble "Canga"

Fossiliferous sandy shale

Sands and clays

Lignitic shale

Weathered gneissic granite
with pegmatite
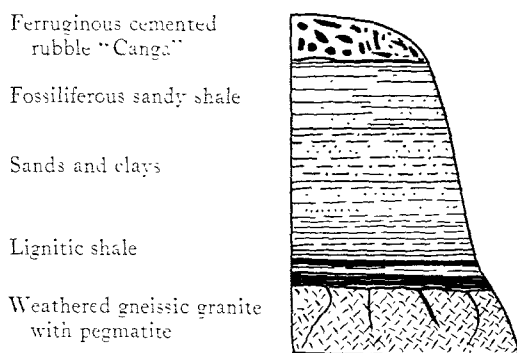
FIG 1.   Graphic section of plant bearing outcrop at Fonseca (slightly modified from Gorceix).

I do not know, but that it is approximately to scale is indicated by his giving the thickness of stratum 2 as 5 meters and

stratum 3 as 22 meters. The fossil plants are supposed to have come from stratum 2.

The following species are represented:

Arrabidea sp.
Banisteria oblongifolia, new
Cæsalpinia echinataformis, new
Cassia fonsecana, new
Cassia obtusatafolia, new
Cedrela campbeli, new
Combretum fonsecanensis, new
Erythrochiton bahiense Hollick & Berry
Homalanthus prenutans, new
Jacaranda tertiaria, new
Labatia fonsecana, new
Myrsine braziliana, new
Sapindus presaponaria Hollick & Berry
Sapindus sp.
Siparuna preguayensis, new
Terminalia maxima, new
Triptolemæa tertiaria, new

Of these 17 species 2 are common to the Pliocene of Bahia and the balance are new to science. Gorceix speaks (op. cit.) of the foliage of Mimosaceæ and of Melastomaceæ as being especially common at Fonseca. In the material that I have seen neither of these families is represented.

If the reader is sufficiently interested to read the discussion of geographic and geologic distribution given under the systematic discussion of species, he will see that with the exception of the fossil form referred to the euphorbiaceous genus *Homalanthus,* all are very similar and presumably related to still existing species in the Brazilian region.

Homalanthus in the modern flora has about a dozen species found in Ceylon, through the Malayan region to the Philippines and Australia and on the larger of the Pacific islands. It is unknown in South America nor is it otherwise certainly known in the fossil state. With respect to its occurrence

as a fossil in the later Tertiary of Minas Geraes there seems to me to be but three possibilities: (1) that the fossil is wrongly identified, to be correlated with the view of many botanists that all leaves are incapable of identification; (2) that it represents an extinct genus related to *Homalanthus*, *Sapium*, *Stillingia* and perhaps other existing genera of the family Euphorbiaceæ; (3) that *Homalanthus* was present in South America as late as the closing days of the Tertiary, or indeed may be found in future exploration in what is after all an imperfectly known region botanically, to be still existing in this region.

Whatever the true answer to this problem it seems to me that the striking resemblance of all of the fossil plants thus far known from Fonseca to Recent species and 16 of the 17 identified forms to still existing species of the same region may be considered to indicate that the fossil assemblage is not very ancient. From the presence among the Fonseca plants of two species—the *Erythrochiton* and *Sapindus*—which are common to the Bahia flora and in turn the probability of the Bahia flora having been Pliocene in age, I am disposed to regard the Fonseca flora as of approximately the same age, namely, Pliocene.

It should not be lost sight of that the Fonseca flora might even be Pleistocene and correspond in age to the cave faunas of Brazil described by Lund who considered them to be Pleistocene. On the other hand these faunas are probably not synchronous with one another, nor is it certain that Pliocene and Pleistocene faunas can be sharply differentiated; I certainly do not feel that this has been done successfully at certain classic mammalian localities such as Tarija and Ulloma in Bolivia or Catamarca in the Argentine not to mention the difficulties of correlation of the Patagonian mammalian horizons.

The presence of the genus *Homalanthus* at Fonseca, if this is admitted, would seem to me to indicate a Pliocene age.

In regard to ecological considerations which may be deduced from the plants described from Fonseca, the smallness

of the number known would render abortive any attempt at precision, so that the amount of material does not merit the labor of making the attempt. At the present time in Minas Geraes there are great variations in climatic elements and consequently in the plant cover according to altitude and situation, *i.e.* exposure, slope, valley floor, etc. It is quite possible that the fossil plants thus far identified do not come from a single ecological assemblage. There are some reasons for thinking that this is so but I do not see how this could be verified without studying extensive collections. All the fossil forms are obviously tropical and the majority are wet tropical. There is a conspicuous number of genera which are represented in modern floras in coastal situations such as beaches (*Coccolobis, Sapindus, Terminalia*) or mangrove associates (*Combretum, Labatia*) but in all these cases the genera have many other species not distinctly coastal so that I do not believe that this is of any significance in the present connection.

Large genera, like *Cassia*, occupy all kinds of situations and are of no significance. The *Jacaranda* is most like existing *Campos* species and *Arrabidæa* may occur in wet or dry situations, but so may the majority of the genera mentioned.

What this amounts to is what I have already stated, *i.e.* the evidence is insufficient for any reliable conclusions, other than it indicates a tropical assemblage.

Monocotyledonæ
    Scitaminales
        Musaceæ
            Heliconia bahiana
Dicotyledonæ
    Polygonales
        Polygonaceæ
            Coccolobis preuvifera
    Rosales
        Cæsalpiniaceæ
            Cassia fonsecana
            Cassia obtusatafolia
            Cæsalpinia echinataformis

Papilionaceæ
    Triptolemæa tertiaria
Geraniales
   Rutaceæ
    Erythrochiton bahiense H. & B.
   Meliaceæ
    Cedrela campbeli
   Malpighiaceæ
    Banisteria oblongifolia
Euphorbiales
   Euphorbiaceæ
    Homalanthus prenutans
Sapindales
   Sapindaceæ
    Sapindus presaponaria H. & B.
    Sapindus sp.
Laurales
   Monimiaceæ
    Siparuna preguayensis
Myrtales
   Combretaceæ
    Combretum fonsecanensis
    Terminalia maxima
Primulales
   Myrsinaceæ
    Myrsine braziliana
Ebenales
   Sapotaceæ
    Labatia fonsecana
Personales
   Bignoniaceæ
    Jacaranda tertiaria
    Arrabidæa sp.

MONOCOTYLEDONÆ

Order SCITAMINALES

FAMILY MUSACEÆ

Genus HELICONIA Linné

Heliconia bahiana Berry, n. sp.

Plate I, Fig. 4

Leaves relatively small, roughly elliptical in outline, less elongate than the leaves of most existing species. Apex rounded or bluntly pointed. Slightly narrowed to the rounded base. Margins entire. Texture subcoriaceous. Length about 16 centimeters. Maximum width about 8 centimeters. Petiole stout, only the distal moiety preserved. Midvein large and very prominent on the lower side of the leaf. Secondaries numerous, thin, regularly spaced, diverging from the midvein at intervals of 5 millimeters or less at angles approaching 90 degrees, and pursuing practically straight courses to the margins. Tertiaries thin, numerous, their general courses paralleling the secondaries, but not quite so regular as the artist has made them to appear in the illustration, connected by cross veinlets.

Represented in the collections by the type and its counterpart and a second specimen. The matrix has been slightly deformed. I have compared the material with all of the South American Guttiferæ and conclude that it does not represent that family but is a species of the genus *Heliconia*— the American wild banana. *Heliconia* contains about two score existing species in the region between the West Indies and Brazil and is especially common in the rain forests of Central America and in the Montana zone of the Andes as far south as Bolivia, and is also rather generally distributed throughout the Amazon Basin. The only similar fossil form is a Pliocene species from Bolivia.[1]

Occurrence: Marahú, State of Bahia.

Collector: E. Bourdot.

[1] Berry, Edward W. Johns Hopkins University Studies in Geology No. 4, p. 163, pl. 3, fig. 1, tf. 2, 1922.

DICOTYLEDONÆ

Order **POLYGONALES**

FAMILY POLYGONACEÆ

Genus COCCOLOBIS P. Browne

Coccolobis preuvifera Berry, n. sp.

Plate IV, Fig. 1

This striking form is unfortunately represented by the single incomplete specimen figured and its counterpart showing a somewhat greater area of the leaf. The material is insufficient for framing a proper diagnosis, but since it is an entirely new type from the area and seems certainly identifiable, it has been named from its similarity in the leaves to the existing *Coccolobis uvifera* Jacquin, which is found on tidal shores of equatorial America from peninsular Florida to Brazil.

Leaves orbicular or elliptical, coarse and coriaceous, with stout prominent midvein and secondaries. The fragments indicate a length of about 12 centimeters and a maximum width of about 8 centimeters. The secondaries diverge from the midvein at wide angles and sweep upward in regular curves, ultimately becoming parallel with the margins and camptodrome. The tertiary mesh is coarse and well marked including transverse veinlets, usually anastomosing in the midregion or connected near the midvein by veins subparallel with the secondaries. The ultimate veinlets are also well marked and coarse and the areolation is subquadrangular.

The genus goes back to the beginning of the Tertiary, perhaps to the Upper Cretaceous and contains about 125 existing species in the region between southern Florida and Brazil.

Occurrence: Mocambo, State of Bahia.
Collector: Roderic Crandall.

Order **ROSALES**

FAMILY CÆSALPINIACEÆ

Genus CASSIA Linné

Cassia fonsecana Berry, n. sp.

Plate I, Fig. 1

Leaflets small, ovate in outline, slightly inequilateral, with an acuminate tip and a cuneate base. Margins entire. Texture subcoriaceous. Length about 4.25 centimeters. Maximum width about 1.5 centimeters. Petiolule missing, if present in life short and very stout. Midvein stout, straight. Secondaries mediumly stout, regularly spaced, about 8 or 9 camptodrome pairs diverge from the midvein at angles of about 60 degrees. Tertiaries immersed.

This sort of leaflet is of a type which is usually referred to the genus *Cassia* and is so considered, although it is recognized that certainty of identification is impossible. The genus is an enormous one with a great variety of herbs, shrubs and trees, widely distributed in all temperate and tropical regions. The number of fossil species referred to *Cassia* is also very large and range in age from the Upper Cretaceous to the present.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Cassia obtusatafolia Berry, n. sp.

Plate I, Fig. 5

Leaflets small, sessile, elliptical, inequilateral, with a slightly emarginate and distinctly inequilateral apex and a broadly pointed less inequilateral base. Margins entire. Texture subcoriaceous considering the small size of the leaflets. Length about 11 millimeters. Maximum width about 5 millimeters. No trace of petiolule. Midvein relatively stout, prominent and straight. Secondaries about 5 or 6 pairs, rather straight to near the margins where they are abruptly camptodrome. Tertiaries well marked, merging in the

secondaries and forming mostly angular junctions, the mesh being elongated parallel with the course of the secondaries.

Several detached leaflets of this species are contained in the collection, and they are named from their very great similarity to the leaflets of the existing *Cassia obtusata* Hayne of the Brazilian region. *Cassia* is a very large genus not only in the existing flora, but in Tertiary floras generally, and many forms could be mentioned which resembled the present fossil, and this is particularly true of the numerous leguminous leaflets in the Pliocene flora of Potosi, Bolivia.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Genus CÆSALPINIA Linné

Cæsalpinia echinataformis Berry, n. sp.

Plate II, Figs. 1 to 4

Leaves fairly large, probably bipinnate. It has been impossible to determine the habit conclusively. The best material (that photographed) shows the pinnate habit very well, but whether these are whole leaves or the pinnæ of a larger bipinnate leaf is uncertain. The rather poor specimen shown by a drawing suggests that the complete leaf may have consisted of 4 or 5 such pinnæ as the specimens photographed. Pinnæ oblong, evenly pinnate, of numerous, rather closely spaced, opposite leaflets. Actual traces of 17 pairs are shown in the more complete specimen and it is estimated that the total number in this specimen was 20 or 21 pairs. Leaflets practically sessile, somewhat variable in size, slightly smaller both proximad and distad, oblong-ovate in outline. Tips truncately rounded or slightly emarginate, and nearly equilateral. Base markedly inequilaterally rounded, widest on the distal side. In the larger specimens the base of the midvein expands into what may be considered a petiolule, but it is not seen in most specimens and is never over a millimeter in length. The margins are entire, full and even, and the texture is markedly coriaceous. The attitude of the leaflets with

respect to the rachis varies from about 45 degrees distad to as much as 70 degrees proximad. Midveins stout and prominent, particularly on the under side of the leaflets. Viewed from the upper side the secondaries are nearly obsolete by immersion in the leaf substance; they are more prominent on the lower side and are seen to be numerous, closely spaced and subparallel, diverging from the midvein at wide angles, and camptodrome in the marginal region. The tertiaries cannot be made out.

On the whole this material may be said to be more satisfactory than is usual among fossil Leguminosæ. Two living genera seem to be closest to the fossil. These are *Enterolobium*, a small genus of tropical American trees, and *Cæsalpinia*. The latter appear to me to show the most homologies, and the present species is named from its resemblance to the recent *Cæsalpinia echinata* Lamarck, a tree of the present Brazilian region. The only difference between the two is the somewhat fewer number of leaflets per pinna in the recent form.

It cannot be denied that in this large alliance resemblances could be pointed out to many and unrelated genera, as for example the North Temperate genus *Gleditsia*, but such a comparison in a tropical assemblage of late Tertiary fossils from Brazil, needs but to be mentioned to indicate its absurdity.

The genus *Cæsalpinia* comprises upwards of 50 existing species of trees or climbing shrubs, and is widely distributed in the tropics of both hemispheres. Fossil forms are known as early as the Upper Cretaceous of North America and by Eocene time the genus had reached Europe. The Tertiary paleobotanical history of the Asiatic and American tropics is so little known that no general statement is possible at the present time.

Occurrence: Fonseca, state of Minas Geraes.
Collector: A. Mello Campbel.

FAMILY PAPILIONACEÆ

Genus TRIPTOLEMÆA Martius

Triptolemœa tertiaria Berry, n. sp.

Plate IV, Fig. 2

There is no doubt but that this form represents a leaflet of some one of the alliances of the Leguminosæ, and after a thorough canvas of the genera which contain somewhat similar leaflets it appears to represent *Triptolemœa*. It may be described as follows:

Leaflets elliptical-ovate, slightly inequilateral, with a rounded base and a narrowed but rather obtusely pointed tip. Margins entire. Texture extraordinarily coriaceous. Length about 5 centimeters. Maximum width about 2.6 centimeters. No petiolule is preserved, and the leaflets may well have been sessile. Midvein stout, prominent on the under side of the leaflet, slightly curved distad. Secondaries largely immersed in the leaf substance, numerous, diverging from the midvein at angles of about 45 degrees, curved ascending, camptodrome. Tertiaries indistinct.

The genus *Triptolemœa* of Martius is frequently made a section of *Dalbergia*, as by Taubert in Engler & Prantl, and there is no doubt that a close relationship exists between the two. It contains about 25 existing species, two thirds of which are old world. No fossil species have heretofore been recognized, but *Dalbergia*-like leaflets and fruits definitely go back to the dawn of the Tertiary and probably to the mid-Cretaceous.

The present fossil form is most like the leaflets of the existing Brazilian species *Triptolemœa glabra* Bentham, and this resemblance is remarkably close. Other similar Brazilian species are *T. montana* Martius and *T. latifolia* Bentham.

Occurrence: Fonseca, State of Minas Geraes.

Collector: A. Mello Campbel.

Order **GERANIALES**

FAMILY MELIACEÆ

Genus CEDRELA Linné

Cedrela campbeli Berry, n. sp.

Plate V, Fig. 1

Leaflets large, inequilateral, elongate ovate, with an acute tip and a rounded base. Margins entire. Texture coriaceous. Length about 10 centimeters. Maximum width about 3.75 centimeters. Petiolule stout, about a centimeter in length. Midvein stout, prominent, slightly curved. Secondaries largely immersed, about 8 pairs, somewhat unequally spaced, diverging from the midvein at angles of more than 45 degrees, camptodrome. Tertiaries obsolete. Species named for the collector.

This leaflet is almost identical with those of the existing Antillean species *Cedrela odorata* Linné. The genus goes back to the dawn of the Tertiary and contains about a dozen existing species confined to tropical America.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

FAMILY MALPIGHIACEÆ

Genus BANISTERIA Linné

Banisteria oblongifolia Berry, n. sp.

Plate IV, Figs. 3, 4

Leaves oblong in general form, widest medianly and about equally tapering to the acute apex and base. Margins entire. Texture coriaceous. Length between 11 and 12 centimeters. Maximum width about 4.2 centimeters. Petiole missing. Midvein stout, prominent, curved. Secondaries stout, prominent, numerous, uniformly curved, irregularly spaced; diverging from the midvein at angles usually greater than 45 degrees, ascending and camptodrome in the marginal region. Ter-

tiaries thin, comprising subsecondaries and transverse veinlets forming an open more or less quadrangular mesh. Ultimate areolation obscure.

The fossil resembles the leaves of several existing species of the genus, which has its headquarters in the wetter Brazilian region. The modern species number about 80, mostly climbing shrubs and confined to the American tropics. *Banisteria* occurs as fossils as early as the lower Eocene.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

FAMILY RUTACEÆ

Genus ERYTHROCHITON Nees & Martius

Erythrochiton bahiense Hollick & Berry

Erythrochiton bahiense Hollick & Berry, Johns Hopkins University Studies in Geology, No. 5, p. 70, pl. 5, fig. 4, 1924.

This species was based upon incomplete material from the Pliocene of Bahia. It was described as follows:

"Leaves of large size, obovate-lanceolate in general outline, widest above the middle, pointed at both ends, gradually narrowed proximad. Margins entire, evenly rounded. Texture coriaceous. Length about 17 centimeters. Maximum width about 6.5 centimeters. Petiole missing. Midvein stout and prominent. Secondaries stout and prominent, evenly spaced, subparallel, and camptodrome: diverging from the midvein at wide angles and regularly curved upward. Tertiaries obsolete."

A single specimen from Fonseca is more complete than the type but is lacking in information regarding certain features.

The genus is limited in size and comprises small trees which range from Central America to southern Brazil. The fossil appears to be most like the existing *Erythrochiton brasiliense* Nees & Martius a forest form ranging from the southern states of Brazil northwestward to eastern Bolivia and Peru.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **EUPHORBIALES**

FAMILY EUPHORBIACEÆ

Genus HOMALANTHUS Jussieu

Homalanthus prenutans Berry, n. sp.

Plate V, Fig. 6

Leaves average to small in size for the genus, deltoid to cordate in outline, widest near the base, tapering upward to the acute tip. Margins entire, not evenly full and curved. Texture of considerable consistency, but not coriaceous. Length about 5 centimeters. Maximum width about 4.3 centimeters. Petiole stout, its length unknown. It is preserved for a length of about a centimeter but is obviously broken. The existing species have long petioles. Midvein mediumly stout and prominent. Secondaries mediumly stout, about 5 regularly spaced and mostly alternate pairs; they diverge from the midvein at angles of 45 degrees or more, and are curved and camptodrome.

The lower pair and sometimes the second pair give off on their outer side several sweepingly curved, camptodrome branches. The tertiaries are thin, percurrent over short distances, but mostly inosculating in the mid-region between adjacent secondaries. Areolation mostly indistinct, sub-quadrangular.

This form shows some rather remote similarities to certain existing species of *Sapium* and *Stillingia*, but finds its closest affinity with various species of *Homalanthus* as for example, *Homalanthus populneus* (Geisl.) Pax of the Philippines, *Homalanthus populifolius* of the Australian region and *Homalanthus nutans* (Forst.) Pax of the Pacific Islands. The last is extremely like the fossil in every respect and has suggested its name. Selected specimens in the other two species mentioned are also scarcely distinguishable from the fossil. Other species, as *Homalanthus fastuosus* F. Vill. of the Philippines, have leaves which often match the fossil in every respect except that they are perfoliate.

The genus contains about a dozen existing species of shrubs or trees.   It is no longer found in South America but occurs on the larger Pacific Islands, in Ceylon, and from the Malayan islands through the East Indies to Australia.   The only other fossil record is a not very convincing one by Ettingshausen [1] from the Miocene of Bohemia.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **SAPINDALES**

FAMILY SAPINDACEÆ

Genus SAPINDACEÆ

Sapindus presaponaria Hollick & Berry

Sapindus presaponaria Hollick & Berry, Johns Hopkins
   Studies in Geology. No. 5, p. 82, pl. 8, figs. 6, 7, 1924.

An incomplete leaflet agrees with this species which was described originally from Aramarý, Bahia.   The present material adds nothing to our knowledge.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Sapindus sp.

A single incomplete specimen of what appears to be a leaflet of this genus indicates a relatively small and narrow form, ovate in outline, much more narrowed distad and acuminate than the preceding.   Length between 7 and 8 centimeters.   Maximum width about 2.2 centimeters.   It is somewhat inequilateral, with a narrow midvein, ascending camptodrome secondaries and subcoriaceous texture.   Too incomplete to be of any importance other than indicating an additional type in this interesting flora.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

[1] Ettingshausen, C. von.   Foss. Fl. v. Bilin, Th. 3, p. 44, pl. 50, fig. 27, 1869.

Order **LAURALES**

Family Monimiaceæ

Genus Siparuna Aublet

Siparuna preguayensis Berry, n. sp.

Plate V, Fig. 2

Leaves oblong-ovate, apiculate. Margins entire. Leaf substance thin and apparently stiff. Length about 8 centimeters. Maximum width about 3 centimeters. Petiole missing. Midvein mediumly stout and not especially prominent. Secondaries thin, about 9 pairs, diverging from the midvein at angles of 45 degrees or more, subparallel, camptodrome. Tertiaries indistinct.

The single specimen upon which this species is based, was evidently in the water for some time before it was covered by sediment as it is largely riddled by the attacks of what were probably aquatic insect larvæ. It is intimately associated with *Jacaranda tertiaria* and *Cassia obtusatafolia*. It is practically identical in all of its features with the leaves of the existing *Siparuna guayensis* Aublet, which similarity has suggested the specific name.

Siparuna, with numerous existing species, is confined to the American tropics. It has hardly been recognized in the fossil state, largely I believe because of the unfamiliarity of paleobotanists with the foliage of the Monimiaceæ.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **MYRTALES**

Family Combretaceæ

Genus Combretum Linné

Combretum fonsecanensis Berry, n. sp.

Plate V, Fig. 7

This species is based upon a single specimen with missing tip (No. 1551) and its counterpart (No. 1546). These indicate

a medium sized leaf, rather smaller than the average in this genus. It is elliptical or elliptical-lanceolate in outline, with a semicircular and somewhat inequilateral base and a missing tip which may have been either rounded or pointed. Margins entire. Texture coriaceous. Length (estimated) about 10 centimeters. Maximum width 5 centimeters. Petiole stout, expanded, about 8 millimeters in length. Midvein stout, prominent, curved. Secondaries numerous, stout, somewhat irregularly spaced, diverging from the midvein at wide angles, about 60 degrees, camptodrome. Tertiaries immersed.

There are a number of existing species in South America rather similar to the present fossil. The genus contains about 130 existing shrubs and trees, many of coastal habitats. They are found in all tropical countries except Australia and Polynesia, and about ⅓ are endemic in South America. Fossil species are known from the lower Eocene onward, and the genus appears to have been of American origin at the dawn of the Tertiary. A fossil form is known from the lower Miocene of Chile, but the paleobotanical history of South America during the Upper Cretaceous and Tertiary is so little known, that it will be a long time before any details of this history can become known.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Genus TERMINALIA Linné

Terminalia maxima Berry, n. sp.

Plate III

Leaf of a very large size, oval or slightly obovate in general outline, with a bluntly pointed tip and a broadly cuneate base. Margins entire. Texture relatively thin for so large a leaf. Length about 28 centimeters. Maximum width about 13 centimeters. The leaf is somewhat inequilateral, to what an extent it is impossible to determine since the marginal region is gone on one side. Petiole not preserved. Midvein stout and

prominent throughout its length, but not relatively stout considering the size of the leaf. Secondaries fairly regularly spaced, stout and prominent; they diverge from the midvein at wide angles, in the neighborhood of 65 degrees, are rather evenly curved and ultimately camptodrome, some of the lower ones give off one or more distal, outside, camptodrome branches. The internal tertiaries are simple and percurrent in rare instances where the distal portions of the secondaries approach closely; generally they are somewhat curved, their courses approximately at right angles to the secondaries and extend half of the distance between the secondaries, the ends being connected by angular zig-zag nervilles; or they may extend all the way across the space between adjacent secondaries with numerous, more or less straight cross nervilles between adjacent tertiaries; or the one type may grade into the other. Ultimate areolation indistinct.

This species is based upon the single incomplete specimen figured and a very poor counterpart.

The genus contains over 100 existing species of trees, found in all tropical countries and extending into some subtropical regions. The most similar existing species is *Terminalia catappa*, the so-called almond, common in coastal tropical regions. Fossil species, represented by both leaves and fruits, are present from the lower Eocene onward, especially in the early Tertiary of the southeastern United States and along the expanded Tertiary seas of southern Europe. Species comparable with the present fossil form occur in the middle Eocene of the southern United States and in the Oligocene of northern Italy. Fossil species are known from the late Miocene of northern South America and the characteristic winged fruits occur in the Pliocene of Bolivia.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **PRIMULALES**

FAMILY MYRSINACEÆ

Genus MYRSINE Linné

Myrsine braziliana Berry, n. sp.

Plate IV, Fig. 5

Leaves lanceolate, not entirely equilateral, with acuminate tip and acute base. Margins entire. Texture coriaceous. Length about 10 centimeters. Maximum width, about midway between the apex and the base, about 2.7 centimeters. Petiole missing, although there is some indication that it was long and stout. Midvein stout and prominent on the lower surface of the leaf, it is slightly curved in the type. Secondaries numerous and thin, diverging from the midvein at wide angles, camptodrome, the last feature obscured by tertiary branches in the marginal region. Tertiaries indistinct.

The venation is that characteristic of *Myrsine* and the size and form are that of several existing tropical American species of this genus, *e.g. Myrsine ferruginea* Sprengel and *Myrsine myricoides* Schlechtendal. Fossil species are not uncommon from the Upper Cretaceous to the present and the existing species are also numerous and occur, as shrubs or trees, in all tropical regions. Krasser enumerated two fossil species from Bahia in the Hussak collection studied by Ettingshausen: *Myrsine crenulata* and *M. excœcarioides*, both of which are *nomina nuda*. Hollick and Berry described a small obovate or spatulate form from the Pliocene of Bahia as *Myrsine ciliatafolia*.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **EBENALES**

FAMILY SAPOTACEÆ

Genus LABATIA Swartz

Labatia fonsecana Berry, n. sp.

Plate I, Figs. 2, 3

Leaves of small size, lanceolate to oblong-lanceolate in outline, acuminate at both ends. Margins entire. Texture coriaceous. Length ranging from 5 to 10 centimeters. Maximum width ranging from 1 to 2 centimeters. Petiole short and stout, 5 to 6 millimeters in length. Midvein stout and prominent. Secondaries numerous, mediumly stout, diverging from the midvein at angles of more than 50 degrees, camptodrome. Tertiaries obsolete.

This species is represented by 3 incomplete specimens. It appears to be related to the lanceolate species of *Pouteria* and *Labatia*, particularly *Pouteria salicifolia*, *Labatia fragrans* (Dub.) Hassler, and one or two other existing species of *Labatia*.

The genus *Labatia* has upward of 10 existing species of trees in the American tropics. A somewhat doubtful fossil species was described many years ago from the lower Miocene of Germany and there are two similar fossil lower Miocene species in Rio Negro Territory, Argentina, described in the form genus *Pouterlabatia*.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

Order **PERSONALES**

FAMILY BIGNONIACEÆ

Genus JACARANDA Jussieu

Jacaranda tertiaria Berry

Plate V, Figs. 3 to 5

Jacaranda tertiaria Berry, Torreya, vol. 33, p. 38, figs. 1-3
    1933.

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Leaves odd-pinnate, elongate, linear in outline, at least 7 centimeters long and not over 2 centimeters wide, with a distinctly but not prominently alate stipe and at least 14 pairs of leaflets.

Leaflets small, opposite, diverging at wide angles, regularly spaced, somewhat rhomboidal in outline, widest toward the base, more nearly equilateral toward the tip, which is obtusely pointed. Base markedly inequilateral, the proximal side narrowly rounded and connected with the wing of the stipe, the distal side much wider and straighter. Texture subcoriaceous. Margins entire. No traces of pubescence. Length 6 to 7 millimeters. Maximum width 2 to 3 millimeters. Midvein relatively stout and prominent, approximately straight. Secondaries numerous, diverging at wide angles, rather straight to the marginal region and rather abruptly camptodrome.

Fairly complete specimens of this interesting species are available and there can be no doubt of its botanical identity. When it comes to comparisons with individual existing species of *Jacaranda* the relationships are not so clear. This is due to the rather close similarity of several of the small leafed pinnate forms, to considerable variations in the size of the leaves in existing species, and to some extent to variations in form of the leaflets, particularly as to the acuteness of the tips.

Among the most similar existing species are *Jacaranda brasiliana* Persoon—a Campos undershrub, *Jacaranda mimosæfolia* D. Don of southern Brazil and northern Argentina, and *Jacaranda filicifolia* (Anderson) D. Don of the lower Orinoco and Guiana region. In some respects the last is the most similar, although there is little difference in the degree of resemblance of the three. *Jacaranda filicifolia* is apt to be more acutely tipped, although not invariably so, is apt to be slightly larger, and invariably has fewer leaflets, at least in the material that I have seen. This last statement is also true of *Jacaranda brasiliana*. In this feature *Jacaranda mimosæfolia* is most like the fossil.

The genus has about two score existing species, ranging in

size from undershrub and chapparal growth of the Brazilian Campos to large trees of less dry regions. The area of distribution extends from the Bahamas and Central America to northern Argentina and from the Maranon valley in Peru and the Montana zone of the central Andes to the Atlantic. It is unfortunate that the evidence of relationship to existing species is not more conclusive. The balance of the evidence is slightly in favor of *Jacaranda mimosæfolia* or *filicifolia* rather than the more typical Campos species, although there is nothing conclusive about these comparisons.

But two other fossil species have been referred to *Jacaranda*. These are *Jacaranda potosina* Berry[1] from the Pliocene of Bolivia and *Jacaranda borealis* Ettingshausen[2] of the Oligocene (Sannosian) of the Tyrol, the latter based upon both leaflets and seeds. Neither of these can be considered to be entirely beyond doubt. It may be repeated that I regard *Jacaranda tertiaria* as botanically beyond suspicion.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

<center>Genus ARRABIDÆA P. De Candolle</center>

<center>*Arrabidæa* sp.</center>

<center>Plate V, Fig. 8</center>

There is a single fragment of a leaflet (if the identification is correct) entirely too incomplete for a proper description, which almost certainly represents a species of *Arrabidæa*. It indicates an ovate leaf of a length of about 8 centimeters and a maximum width of 4.25 centimeters, with entire margin, thin texture, slender but prominent midvein and thin, ascending, camptodrome secondaries.

Except for its somewhat smaller size it is much like a species[3] described from the lower Miocene of Chubut Terri-

[1] Berry, Edward W. U. S. Natl. Museum Proc., vol. 4, p. 160, pl. 18, fig. 14, 1917.
[2] Ettingshausen, C. von. Tertiarflora von Haering, p. 59, pl. 20, figs. 12–20, 1855.
[3] Berry, Edward W. Johns Hopkins University Studies in Geology No. 6, p. 227, pl. 8, fig. 2, 1925.

tory, Argentina, and is like the existing *Arrabidæa caleocalyx*
B. & S. and *Arrabidæa triplinervia* var *genuina* of southern
Brazil.

The genus consists of about 50 existing species of climbing
shrubs with 2 or 3 foliate leaves, which are confined to South
America and to a large extent to middle and southern Brazil.

Occurrence: Fonseca, State of Minas Geraes.
Collector: A. Mello Campbel.

PLATE I
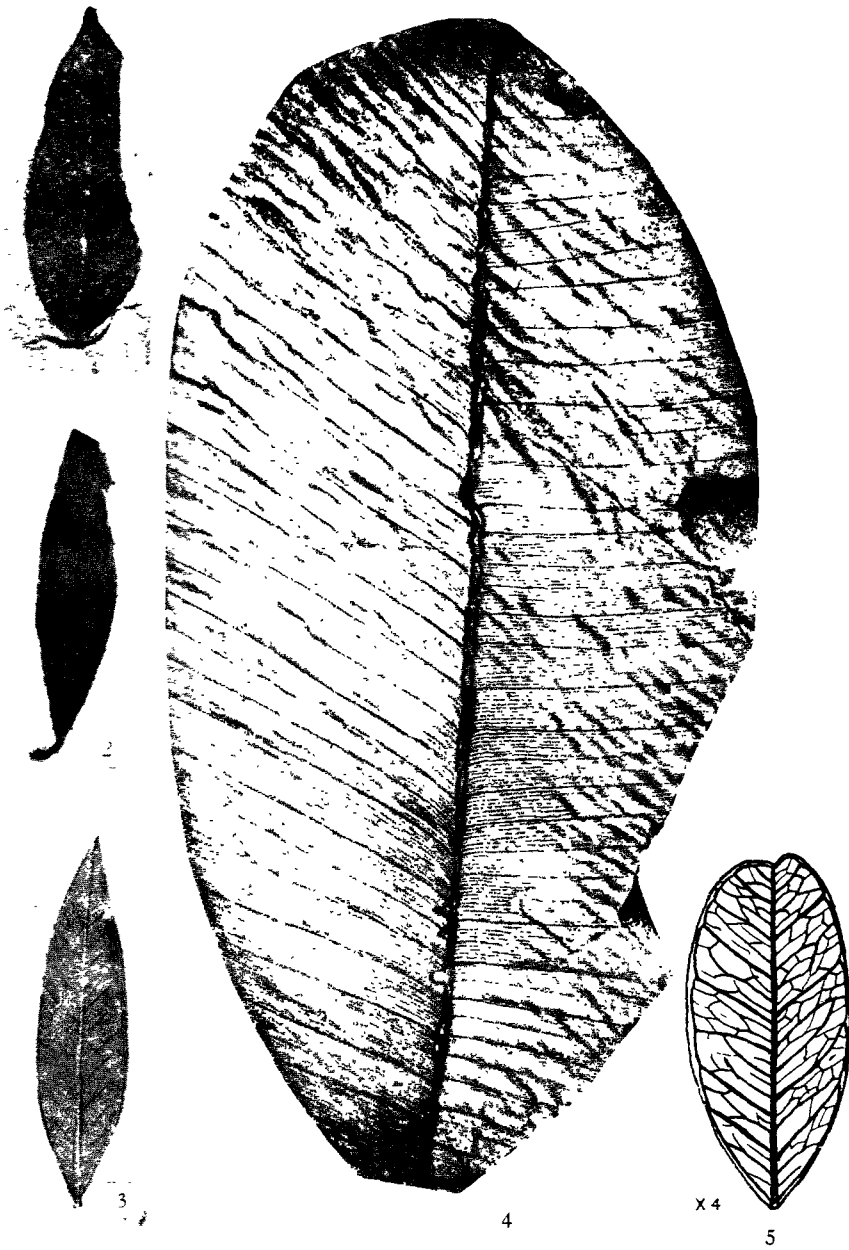
PLATE II

FIGS. 1-3. *Caesalpinia acutifolia* Berry, n.sp.   Fonseca, Minas Geraes
FIG. 4.   Possible restoration of preceding, much reduced.

PLATE III

Terminalia maxima Berry. n.sp.. 2/3 nat. size   Fonseca, Minas Geraes.

PLATE IV

PLATE V
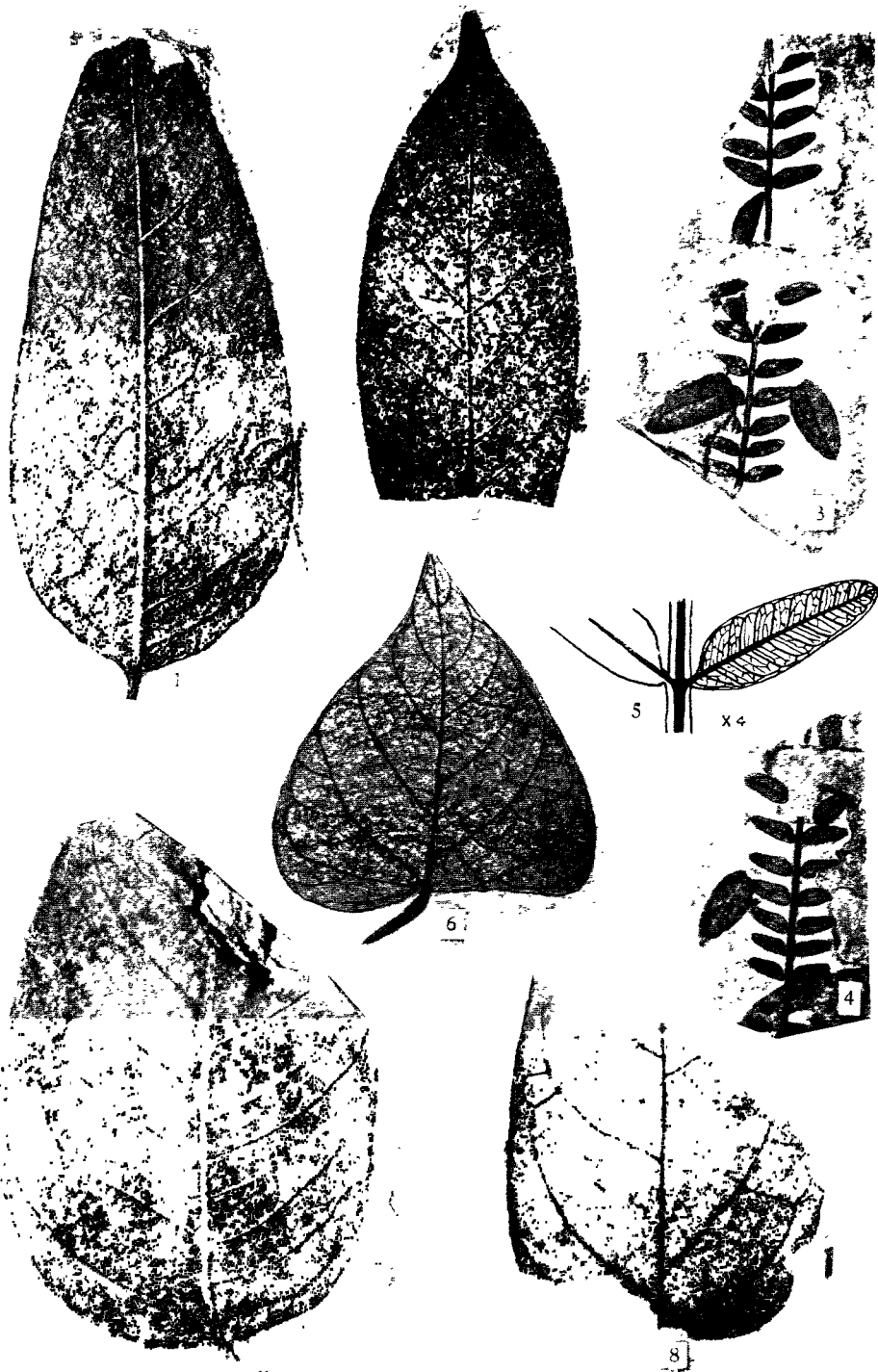
FIG. 1   *Cassia* ...... Berry, n sp.
FIG. 2.   *Separata* .... Berry, n sp
FIGS. 3, 4   *Jacaranda* .... Berry
FIG. 5   Enlargement of the preceding to show venation and other features
FIG. 6.   *Hemadanes* .... Berry, n sp
FIG. 7   *Cubreum* .... Berry, n sp
FIG. 8   *Anal* ...... sp

All from Fonseca, Mir... Gerxes.

SLAVONIC LOAN MATERIAL IN HUNGARIAN

J. DYNELEY PRINCE

HUNGARIAN is the language of the people, basically of Mongolian origin, who call themselves "Magyars" and who occupy the territory of the present curtailed Hungarian king-less monarchy as well as some of the regions taken from pre-war Hungary and assigned to Czechoslovakia, Yugoslavia, and Rumania. Their language, the Magyar, belongs to the Finno-Ugric linguistic family which exists not only in the Hungarian-speaking lands, but in Russia, Finland, Estonia, and the northern parts of Sweden and Norway. A sharp division is made between the Finnic and the Ugric idioms which are represented by the Magyar, the Vogul of the former Russian Departments of Perm and Tobolsk and the Ostiak group also in the former Russian Department of Tobolsk east of the Voguls. The Voguls number only some 5000 souls while the Ostiaks have a population of about 18,000. They are both usually classified as the Ob-Ugrians from the name of the River Ob. The other Finno-Ugric languages belong to the Finnic family which includes of course Finnish, Estonian, and Lappish, and differ considerably from the Ugric groups, both phonetically and grammatically.

The present Magyar language with which this paper is exclusively concerned is usually divided into eight so-called dialects which, however, as they are all mutually intelligible, are rather to be designated as phonetic variants. They are as follows: (1) the Western; (2) Trans-Danube; (3) Alföld; (4) Danube-Theiss; (5) Northwestern; (6) Northeastern; (7) Trans-Kömogsteich; and (8) the idiom of the Széklers and that of the settlers in the Rumanian Bukovina.

The Hungarian language, although rich in foreign material,

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has not really changed its vocabulary or grammar nearly as much as is the case with French, English, or even German, during the historical period, which in the case of Hungarian dates from the eleventh century when the first written records appear. Thus, from the year 1055 on, we find numerous Hungarian words of the period in Latin documents. The first connected text, however, is a funeral oration consisting of only 300 words which dates from the first quarter of the thirteenth century. The list of more comprehensive material in manuscripts and codexes of religious content begins with the Ehrenfeld-Codex from the first half of the fifteenth century but most of these date from the first decade of the sixteenth century. These, however, and also earlier similar documents are chiefly copies of still older codexes. The first book in Hungarian was not printed until 1533.

There can be no doubt that the Hungarian language during the course of unknown centuries took much material from other linguistic stems and also that this borrowing began long before the occupation by the Magyars of present Hungary, which took place in A.D. 985–986. Thus there are unmistakable traces of cultural contact between the early Magyars and various Iranian tribes which began most probably in the prehistoric period. Some of these Indogermanic roots are found in many other Finno-Ugric languages, as may be seen from the following examples. Thus we find Hung. *víz*, water, and Finn. *vete-*, Chuvash, büt, etc. = Indog. **ved-*, seen in Germanic *wet, water (wasser)*, etc. (Phrygian βεδυ). Similarly the words in Finno-Ugric for honey and wine show very early borrowings from Indo-Germanic; thus Hung. *méz*, honey, Finn. *mete-* Lap. *mitt* = Indog. *medha*, honey, wine; Sans. *mádha-* honey-wine still known as *metheglin* (*meth-) in Welsh = Eng. *mead*, etc. *Cf.* also the Finno-Ugric words for salt: Hung. *só(l)*, Finn. *suola*, Mordvin *sal* = Lat. *sel*, Old Sl. *sol*, etc. Further examples of such apparently prehistoric borrowing by practically the entire Finno-Ugric group are succinctly but clearly discussed by J. Szinnyey (Finno-ugrische Sprachwissenschaft, Leipzig, 1910, p. 20f).

The object of this paper is to deal specifically although necessarily briefly with the Slavonic loanwords in Hungarian proper. There can be little doubt, according to the recognized authorities on this subject that long before the Magyar occupation of Hungary, these people had come into contact, not only with a Finno-Ugric tribe in the Volga region from whom the Magyars learned many agricultural and domestic animal words, but also with primitive Slavs chiefly of the Russian variety from whom certain old Slavonic words were borrowed. It is clear, however, that the majority of Slavonic borrowings took place after the rise of the first Hungarian kingdom under Arpad and that this material was taken from Old Church Slavonic, Russian, Serbo-Croatian, and Slovak sources. Furthermore, after the year A.D. 1000 a considerable amount of German material was absorbed mostly from Frankish, Austrian, and Bavarian sources with which the Magyars came into contact. Of course, the Turks also contributed to the Magyar vocabulary during the long period of their occupation of Hungary and last but not least, we have the influence of ecclesiastical Latin beginning after the conversion of the Hungarians to Christianity and continuing for centuries under the influence of the conversational Latin which soon became the cultural idiom of the country. In fact, within the writer's own memory, older cultivated Hungarians were still able to converse in Latin.

Hungarian has adopted very few Slavonic morphological endings. Perhaps the most noticeable of these is -nok(nök) denoting the agent as bajnok, warrior = Sl. vojnik, soldier (but more probably derived from an old form bojnik). Most of the Slav words as used in Magyar to-day are mere phonetic variants based upon certain principles hereinafter tabulated. It should be noted that Magyar differs in this respect from Turkish which has thousands of Arabic and Persian loanwords, most of which have become Turkized in pronunciation with comparatively little drastic alteration of vowels or consonants. Such loanwords are perfectly recognizable in Turkish even to the ear, while many Magyar Slav words in common use are unrecognizable to a Slavonic ear.

As stated above, during the last millenium, the Magyars have been in contact with nearly all the Slavonic languages at the various stages of their development and if we would prepare a complete list of vowel changes, it would be necessary to trace the history of each borrowing to the definite Slavonic idiom and the definite period when it was made. This would involve many difficulties since for some languages as Slovak we have very scanty material dating from the first centuries of their contact with the Hungarians and we are faced also with the problems involved in the Church Slavonic idioms and in the folk dialects of many of the Slavonic groups.

As an example of this we may remark that the indeterminate vowel is represented in Serbo-Croatian usually by a. In Russian it is represented by o or e, in Czech and Slovak by e, etc. Thus S–Cr. lav, lion, Russian lev, CS, lev, etc. The same situation prevails in regard to the quantity of the Slavonic vowels and also to the amount of palatalization in the different languages. Serbo-Croatian is much harder than Russian, not to speak of Polish, etc.

All this does not interfere with the certainty of the borrowing and therefore we will endeavor to indicate some of the changes that we find with especial reference to the forms in Serbo-Croatian.

Vowel Changes

M.	Sl.	M.		Sl.	
a	e	csap		čep	
			tap, spiggot		stopper, plug
		vacsora		večera	
			supper		
a	o	galamb		golub, Ch. Sl. Golъbъ Pol. gołąb	
			dove		
		ablak		oblok	
			window		
		abrak		obrok	
			provender		portion, share
á	ja	árok		jarok	
			ditch		
á	a	bába		baba	
			midwife		old woman, (babica- midwife)
á	o	áko		oka	
			a measure (Tk. oqa)		
e	a	len		S–Cr. lan, but CS. len	
			flax		

M.	Sl.	M.		Sl.	
e	l	tányér		tanjir	
			plate		
e	o	ebéd		ob(j)ed	
			dinner		
e	u	eszterga		struga	
			lathe		plane
ı	e	kalitka		S-Cr. krletka R. kljetka	
			cage		
i	o	viasz		vos(ak)	
			wax		
i	u	kukorica		kukuruza but C kukuřice	
			maize		
o	a	bot		bat	
			stick; cf. M. sétabot—walking stick		
o	i	gobanca		gibanica	
			cake, pie		
o	u	csutora		čutura	
			wooden flask		
e	u	csodálatos		čudan	
			wonderful		
		konyha		kuhinja but R, kuhnja	
			kitchen		
		ozsonna		užina	
			supper		
or	r	kormány		krm(ilo) but Ch. Sl. krъma R. kormilo	
			helm		rudder
ö	a	csütörtök		četvrtak	
			Thursday		
ö	vr	csütörtök		četvrtak	
u	e	csütörtök		četvrtak	

Consonant Changes

The consonantal changes are less striking. A few are listed below:

M.	Sl.	M.		Sl.
l	n	tomlóc		tamnica
			prison	
n	l	penész		pliesan
			mould	
s	z	ispán		župan
			governor	
t	c	német		nemac
			German	
t	c	tiszta		čist
			clean	
tty	čk	parittya		praćka
			sling (weapon)	
ty	č	gatya		gaće
			trousers	
ty	šli	borostyán		bršljan (but also brštan)
			ivy	

In addition to such vocalic and consonantal changes as those
just indicated, we observe after an examination of the follow-
ing comparative glossary of two hundred twenty-five Magyar-
Slav *borrowings* loanwords certain other important phonetic
variations to which this class of words has been subjected.
These phenomena may be noted in the following groups:

I. AVOIDANCE OF CLUSTERS

M.		Sl.	
asztal		stol	table
barack		breskva	peach
barát	friend	brat	brother
beretva, borotva		britva	razor
eszterga	lathe	struga	plane (tool)
ganaj		gnoj	pus, dung, matter, manure
gereben	flax-comb	greben	curry-comb
gereblye		greblje	rake
gerenda		greda	beam
giliszta		glista	worm
kalász	spike, ear of corn	kalaš	spike, tuft
kereszt		krst (krest)	cross
király		kralj	king
malom		mlin	mill
oszlop		stup	column, pillar
parittya		pracka	sling
szerencse		sreća	happiness, luck (Pol. szczescie)
veréb		vrabac	sparrow (R. vorobej)

Avoidance of clusters is common also in Finnish in such
loanwords as *rannalla* from Swedish *(på) stranden*—on the
shore.

II. CONTRACTION

daróc	baize	darovac	woolen material
pince	cellar	pivnica	beer cellar
pokróc		pokrovac	coverlet (but O. Sl. pokriv)
tárnok	treasurer	tovarnik	freightclerk (from tovar = goods)
vajda		vojvoda	leader, duke
zár	lock (of gun)	zavor	bar, bolt

III. METATHESIS (NOT UNCOMMON)

kulcs		ključ	key
penész	mould	pljesan	mouldy
szalma		slama	straw
szerda		sreda	Wednesday
szilva		šljiva	plum (but R., C. Sl. sliva)
szolga		sluga	servant

IV. NASALS

The nasalized Sl. words in M. throw light on the history of the nasals, because most of them represent the original nasal of Old Slavonic or of Polish.   Few are probably analogical.

abroncs		obruč	hoop, ring (O. Sl. obrъc)
donga	stave	duga	bow, weapon (O. Sl. dъk, dъga)
galamb		golub	dove (O. Sl. golъb)
goromba		grub	rude, rough
konkoly	coarse eye-grass	kukolj	vetch
péntek		petak	Friday (Pol. piątek)
szalonka		šljuka	kind of snipe
szerencse		sreća	luck, good fortune
szombat		subota	Saturday (O. Sl. sъbota)
szomszed		sused	neighbor (O. Sl. sъsed Pol. sąsiad)

V.   PROSTHESIS

asztal		sto(l)	table. The form asztal (astal) has gone back into Croatian from the Magyar variant of stol
eszterga	lathe	struga	plane
ispan		župan	provincial governor (see above sub consonantal changes)
oszlop		stup	pillar, column

This group is really included in Group I.

It will be observed that the Slavonic forms used in this comparison are chiefly Serbo-Croatian from which language the modern Magyar Sl. material is chiefly taken, although many words have been borrowed from the old and modern Church Slavonic which is also South Slavonic.   These words as well as the numerous German and Turkish loan-material have become so integral a part of Hungarian, that the uninitiated Magyar frequently asserts that such words are originally his own and were borrowed from Magyar by the foreigners.

A list follows of the Sl. loanwords most commonly occurring in the colloquial Magyar of to-day illustrative of the extremely ductile character of the language and its power of absorbing extraneous cultural material.   This quality of Magyar is rivalled only by the same characteristic of English, the vocabulary of which like that of the Magyar is a *mixtum compositum* thoroughly naturalized and established upon a native philological basis.

It may be added in conclusion that the Magyars as a people, although now much mixed racially, have a remarkable capacity for the Magyarization of foreigners. Hundreds of families, largely of Germanic and Jewish origin have thus become so much in tune with the Hungarian culture, that without any compulsion, they have changed their original names into often meaningless Magyar forms and have willingly adopted the native idiom as their own. Perhaps the most striking example of this is the name *Vambery* assumed by the late famous Hungarian philologist whose original name was Bamberg. Many names ending in *-ay* or (soft vowel) *-ey* are of this nature, as *Szinnyey*, *Hennyey*, etc. The intense clannishness of this interesting and tenacious people is therefore not surprising and is paralleled by the equally absorbing Celtic Irish, who have Celticized " Saxon" names, such as *Mannineach* for *Manning*, *Gerdaldin* for *Fitzgerald*, etc. In fact, the Magyar has many of the fiery temperamental traits of the Celt, evidenced not only in patriotism, but in the love for musical extremes seen in the wild wind-like playing of the Hungarian Gypsies, ranging from inconsolable despair to a mad joyousness. Precisely the same phenomenon is seen in the Irish and Scottish-Gaelic music with its wonderful dirges and almost savage dances.

GLOSSARY

ablak		*oblok*	window (*prozor*)
abrak	provender	*obrok*	portion, share
abroncs		*obruč*	hoop, ring
abrosz	table-cloth	*ubrus*	napkin, towel
aczél		*oc(j)el*	steel
akna	shaft, bunghole	*okno*	shaft (R. window)
akó	wine-measure	*oka*	peck (measure) (Tk. *oqa*)
alamizsna		*almožna*	alms
árok		*jarok*	ditch
asztal		*stol* (also *astal*) table	
asztalnok		*stolnik*	joiner
bab		*bob*	bean
bába	midwife	*babica*	midwife (*baba* = old woman)
baj	bother, trouble	*boj*	fight, struggle
bajnok	combatant	*bojnik*	soldier, warrior = *bojnik*
bolha		*buha*	flea

balvány	idol	*balvan*	beam, block, but R. *bolvan*, Cz. *balvan* = idol
bán		*ban*	ban, governor
barack		*breskva*	peach
bara(t)	friar	*brat*	brother, usually *kaludjer* = monk
	M. *szerzetes barat* brother of a monastic order.		
barát	friend	*brat*	brother
barázda		*brazda*	furrow
barkó	whisker	*brk*	mustache, whiskers
beretva	see *borotva*		
bérmálni	to confirm (ecclesiastically)	*bermati*	to confirm
bika		*bik*	bull
borotva		*britva*	razor
borostyán		*bršljan*	ivy
bot		*bat*	stick (as M. *sétabot*—walking stick)

címer	coat-of-arms	*cimer*	sign, shingle (M. *cim*—address, title)

csáklya	grappling-hook	*čaklja*	hook
csap	tap, spiggot	*čep*	stopper, plug, cork
csata	battle	*četa*	band, gang
cseresnye		*trešnja*	cherry-tree (but R. *čerešnya*)
csésze		*čaša*	cup
csodálatos		*čudno*	wonderful
csutora	cigar-holder, wooden flask	*čutura*	flagon, wooden flask
csütörtök		*četvrtak*	Thursday

dajka	wetnurse	*dajka*	teat
daróc	baize	*darovac*	coarse woolen stuff
déd	greatgrandfather	*ded*	grandfather
deszka		*daska*	board, plank
dézsma		*dežma*	tithe
dinnye		*dinja*	melon
donga	stave	*duga*	bow (weapon)
duda		*duda*	bagpipe

ebéd		*obed*	dinner
ecet		*ocat*	vinegar
eszterga	lathe	*struga*	plane

gajdolni		*gajdati*	play the gajda (native bagpipe)
galamb		*golub*	dove
ganaj		*gnoj*	pus, dung, matter, manure
gatya		*gaće*	drawers
gereben	flax-comb	*greben*	curry-comb
gereblye		*greblje*	rake
gerenda		*greda*	beam
gerle		*grlica*	turtle dove
giliszta		*glista*	worm
gobanca		*gibanica*	cake, pie
goromba	coarse, gross	*grub*	rude, rough
görcs		*grč*	spasm, fit

gubó	gall-nut	gubica	snout, gall-nut (guba = lip)
guba	mantle of wollen stuff	guba	cloak
gunya		gunj	blanket

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huszár		husar	hussar. This word is probably a

modification of Cr. gusar = pirate rather than of M. húsz = twenty, i.e. one of a part of twenty.

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ispán		špan	local governor, provincial governor

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jászol	manger	jaslica	crib, manger
jávor		javor	maple

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kád	vat	kada	tub, vat
kakas	cock; also of gun	kokoš	hen M. tyuk hen
kalász	spike, ear of corn	kalaš	spike, tuft
kaliba	hovel	koliba	hut
kalitka		krletka	cage
kamat		kamat	interest (Tk. through Sl.)
kapocs		kopca	hoop, clasp
kása	mush, pap	kaša	pap, porridge
kasza		kosa	scythe
katlan		kotao	kettle, boiler
katulya		škatulja	box
kecsege		kečiga	sturgeon
kereszt		krst	cross
keresztelni		krstiti	christen
kerevet		krevet	bed
király		kralj	king
kocsi		kočija	carriage
kocka		kocka	die (pl. dice)
koma		kum	godfather
komló		hmel	hops
komorna		komornica	lady's maid
komornok		komornik	groom of the chambers
konkoly	eye-grass	kukolj	vetch (= M. abrakborsó)
konyha		kuhinja	kitchen
kopya	pike	koplje	spear (= M. landzsa)
korcsma		krčma	public house
kormány	helm, government	krmilo	rudder
kosár	basket	košara	hamper
kovács		kovač	smith
kovász	leaven	kvas	yeast
konyv		knjiga	book
kucsma	cap with ear-tabs	kičma	back, ridge
kukac	grub	kukac	insect
kukorica		kukuruza	maize
kulcs		ključ	key
kulcsár		ključar	house master, butler
kupa		kupa	cup, goblet

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labda		*lopta*	ball
lakat		*lokot*	padlock
lánc		*lanac*	chain
len		*lan*	flax
lencse		*leća*	lentils
lúg		*lug* or *lusca*	lye

macska		*maćka*	cat
mák		*mak*	poppy
málna		*malina*	raspberry
malom		*mlin*	mill
marha	cattle, stock, goods	*mrha*	cattle
medve		*medved*	bear
megye		*medja*	district of župan, boundary
mérni		*meriti*	measure
mérnök		*mernik*	measurer, surveyor
mészáros		*mesar*	butcher
mocsár		*močvara*	march
molnár		*mlinar*	miller
moly		*molj*	moth
mostoha	step-father or -mother	*maćuha*	stepmother
mozsár		*mužar*	mortar

nádor	palatine	*nadvornik*	high steward, palatine
néma		*nem*	dumb
német		*nemac*	German
nyavalya		*nevolja*	misery (slavery), falling sickness, epilepsy

olom		*oloco*	lead (metal)
oszlop		*stup*	column, pillar

padló		*pod*	flooring, plank
palást		*plašt*	cloak
pálca		*palica*	stick
pap		*pop*	priest, clergyman of any sort
paraszt	peasant	*prost*	simple person, plain person
parittya		*praćka*	sling
paszuly		*pasulj*	bean
patak		*potok*	brook
patkó		*potkova*	horseshoe
pecsenye		*pečenka*	roast meat
pecsét		*pečat*	seal
pelyva	(see *polyva*)		
penész	mould	*pl(j)esan*	mouldy
péntek		*petak*	Friday
pénz		*penez*	money
pince	cellar	*pivnica*	beer cellar
pincér	waiter	(from *pince*); see above	
pióca		*pijavica*	leech
pipacs		*pipac*	a kind of bottle
pogány	heathen	*poganin*	pagan

pót		pauk	spider
pokol		pakao	Hell
pokróc		pokrivac	coverlet
polc		polica	shelf
polyva(pelyva)		pljeva	chaff (dust)
ponyva		ponjava	tarpaulin
posztó	cloth	postava	lining
prósza		proso	millet
puska		puska	gun
puszta		pusta	empty space, desert
pötra		puž	snail
rab		rob	prisoner
raj		roj	swarm (of bees)
rák		rak	crab, cancer
répa		repa	turnip
robot		rabota	statute labour
róna		ravnina	flat land, level place, plain
rozs		rož (Slovak)	rye Cr. hrž
sás		šaš	reeds, rushes
sátor		šator	tent
sisak	helmet	šišak	wild duck; hence helmet from the shape. Cr. kaciga = helmet
suba		šuba	peasant's furcoat
szabad		slobodan, Slov. slobodni free	
szakács		sokač	cook (male)
szalma		slama	straw
szalonka		šljuka	kind of snipe
szalonna		slanina	bacon
szecska		sečka	chopped straw
szekrény		škrinja	box, case
szelence	salt-cellar	solnica	canister (for salt) Cr. Soljenka
szerencse		sreča	happiness, luck
szerda		sreda	Wednesday
szilva		šljiva	plum
szita		sito	sieve
szoba		soba	room, chamber
szoknya		suknja	petticoat
szolga		sluga	servant
szombat		subota	Saturday
szomszéd		sused	neighbour
tábor		tabor	camp
tábornok		tabornik	general, camp-chief
takács		tkalac	weaver (from tkać)
taliga		taliga	cart
tanya	hamlet	stan	dwelling
tányér		tanjir	plate (dinner plate)
tárnok	treasurer	tovarnik	freight agent
tiszta		čist	clean
tolmács		tumač	interpreter

tompa		*tup*	blunt
topoly		*topolj, topola*	poplar
torony		*toranj*	tower
tömloc		*tamnica*	prison

udvar		*dvor*	yard, court
udvarnok	courtier	*dvornik*	door-man, house manager
unoka	grandchild, nephew	*unuk*	grandson
ucsonna (also *ocsonna*)		*užina*	lunch, light meal

vacsora	supper	*večera*	evening meal, supper
vajda		*vojvoda*	military leader, duke
vajdaság		*vojvodina*	duchy; territory between Zemun and the present Hungarian border
vánkos		*vanjkus*	pillow
veder		*vedro*	bucket (note M. *vödór* in *vizvödör*, bucket)
veréb		*vrabac*	sparrow
viász		*vosak*	wax
villa		*vilica*	fork
visnya		*višnja*	cherry
vitéz	warrior	*vitez*	knight

zár	bolt, bar, gunlock	*zavor*	bolt, bar
zab		*zob*	oats
zálog		*zalog*	mortgage
zsana	scold	Cr. *žana* = *žena* female	
zsellér		*željar*	cotter
zsidó		*židov*	Jew

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HOST-PARASITE RELATIONS BETWEEN PARASITIC PROTOZOA AND THEIR HOSTS

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CONTENTS

I. INTRODUCTION

IT IS safe to assume that interest in parasites and their relations to man and other animal hosts has existed for a very

long time, but the discovery of the minute parasites belonging
to the branch of the animal kingdom known as the Protozoa
had to await the development of the microscope.   According
to Dobell (1932), Leeuwenhoek was the first to see and
describe such microscopic parasites, beginning about the year
1674, and he found them in flies, frogs, rabbits and man.
However, general scientific interest in this field did not develop
until the last half of the 19th century.

In recent years the subject of host-parasite relations has
been extensively studied.   It is a very broad subject and may
be approached from many points of view.   In the discussion
which follows it is proposed to consider evidence and interpre-
tations pertaining to certain problems of the origin of para-
sitism among the protozoa and the evolution of these parasites
in relation to the taxonomy of their hosts.

Among parasitologists there appears to be a wide-spread
belief in host specificity, that is, the limitation of each species
of parasite to a particular species of host or to a group of
closely related hosts.   If this were the general rule, there
would naturally result a close parallelism between the evolu-
tionary history of the parasite and that of the host.   In the
two decades of experience that the writer has had in the study
and teaching of protozoan parasitism, there has grown up the
conviction that this idea of the rigidity of host specificity has
too many exceptions to make it a safe guide to the study and
naming of new parasites.   Furthermore, there is much evi-
dence that evolution among and within the groups of proto-
zoan parasites has taken place to a certain degree independent
of host influences of a directive nature.   For example, as
pointed out by Alexeieff (1914) and Becker (1933b) species
belonging to the same genus of parasite are often found in
widely different taxonomic groups of hosts and, on the other
hand, the same species of host may harbor a number of closely
related species of parasites.   These facts suggest that new
species are primarily of mutational origin rather than the
result of any direct effect of the host in a Lamarckian sense.
It is the purpose of this paper to examine and interpret some
of the evidence bearing on these several possibilities.

For the illustrations in this paper the writer has drawn primarily from his own collection of slides. Where drawings have been copied or made from slides supplied by others, acknowledgment is made in the descriptions of the figures. Advantage has been taken of a delay in the completion of the drawings and of the text to include references to literature which has appeared since the original paper was read before the Society. No attempt has been made to provide a complete bibliography. In many instances, where a number of references could be cited, only the most recent ones, or the more comprehensive articles or chapters are cited, and from these, more detailed lists of references can be obtained. In part, the researches on which this paper is based have been aided by grants from the Special Research Fund of the University of Pennsylvania.

II. Host-Parasite Relations in General

1. Types of Association

Associations between organisms of different kinds, where there exists a greater or less degree of dependence of one upon another, or of each upon one another, are wide-spread in nature and may be considered to be perfectly natural, based upon the problem, that every organism has, of securing an adequate food supply (Smith, 1934). The more dependent member of the association, if it be a plant, may belong to any one of most of the major groups from bacteria (perhaps also including filterable viruses) up to flowering plants; and if it be an animal it may belong to any one of many types from protozoa up to mammals.

The larger and more independent of the two associates is commonly called the host while the smaller and more dependent member is commonly called the parasite. If, however, no harm is done to the host, the smaller associate may be called a messmate or commensal and the relation may be referred to as commensalism; and if the two associates are mutually beneficial to or dependent upon each other they are called symbionts and the relation is termed symbiosis. In

the present discussion the term parasite will be used in its broader sense to include any kind of protozoan which is dependent upon a host.

The parasite may be either ectozoic, living on the outside of the host, or endozoic, living within the body of the host. Some parasites are facultative, in that they are capable of living an independent existence if no hosts are available, while others are obligatory, requiring an association with a host in order to complete their life-cycles. Some parasites have temporary associations with hosts while others are permanent parasites, associated throughout their active periods. The following discussion concerns itself primarily with permanent endozoic parasites belonging to the Phylum Protozoa.

2. *Relation to the Body of the Host*

Aquatic animals often have ectozoic protozoa attached to various external parts and endozoic protozoa invade almost every organ and tissue of metazoan hosts. There is, however, a tendency for each kind of parasite to be limited to a particular organ, cavity or kind of tissue, where it normally feeds, reproduces and completes that part of its life cycle which is commonly spent upon or within a host. In the human body, for example, some 25 or more different species of protozoa live as parasites (Hegner, 1928). Some of these are limited to the urogenital tract (*Trichomonas vaginalis*, Fig. 54); others to the digestive tract in which they may be restricted to certain parts thereof, as, for example, the mouth, where there are *Trichomonas elongata* (Fig. 53) and *Endamœba gingivalis*, or to the small intestine, which is inhabited by *Giardia lamblia* (cf. Fig. 50), or to the large intestine where there may be found at least four kinds of flagellates and five kinds of amoebæ besides one kind of ciliate. Some of these live more or less harmlessly in the lumen, while others cling to the cells lining the tract (*Giardia*), or invade the epithelial lining as do the coccidia (cf. Fig. 4), or they may penetrate further into the tissues of the intestimal wall, as in the case

of *Endamœba histolytica* (Fig. 25) and *Balantidium coli* (cf. Fig. 9). Many parasites invade the blood stream where they may attack the blood cells, e.g. parasites of malaria, or may swim in the blood plasma as in the case of trypanosomes (Figs. 44 and 45). Further, they may invade the endothelial cells, as does *Leishmania donovani* (Fig. 49), or they may migrate into the muscles and other organs, as in the case of *Trypanosoma cruzi*.   .

3. Transmission from Host to Host

From any of the invaded regions of the body of the host, the parasite, in order to maintain its species, must leave the individual host and find its way to a new individual host. The methods of transmission are varied but may be summarized as follows.

a. By the activities of the parasite. This applies especially to ectozoic species which may migrate from the exterior of one aquatic host to that of another (*Amphileptus branchiarum*, Fig. 7).

b. By direct transfer. The parasites may pass directly from one host to another when physical contact is made, either accidentally, by osculation (*Trichomonas elongata*, *Endamœba gingivalis*), or by coitus (*Trichomonas vaginalis*).

c. By contamination of the food or drink of the new host. Leaving the immediate host as cysts or spores, or even without a protective membrane in some cases (e.g. trichomonads), a parasite may pass out through natural openings or be released by break down of the host's tissues (external ulcers) or by the death and decay of the host, and may contaminate the food or drink of new hosts, as in the case of most of the intestinal protozoa. After leaving the body of one host, these transmittable stages may pass through the digestive tract of some other animal before reaching a new proper host as has been demonstrated for the cysts of *Endamœba histolytica* (Fig. 26), which may pass through the digestive tract of house flies and then may be deposited upon the food of man.

d. By intermediate hosts. Biting animals often transfer

parasites from one host to another, either by the mechanical method or by the cyclic method. In the former the parasite remains on the mouth-parts of the biting animal and becomes introduced without appreciable change into a new host when the latter is attacked by the biting animal. *Trypanosoma evansi*, cause of surra, a severe disease in domestic animals in India and other regions, is thus transmitted by tabanid flies. In the cyclic method, the parasite undergoes a developmental cycle within the intermediate host so that infective stages result from this development, as in the case of *Trypanosoma gambiense* (Fig. 45) in tse tse flies, in Africa.

e. By invasion of developing eggs or embryos. In this so-called hereditary method the parasite within a female host invades the egg in the ovary or the embryo in the uterus so that the young are infected before leaving the body of the mother. Thus, *Nosema bombycis* of the silk moth invades the eggs in the ovary of the mother.

4. Defenses of the Host Against Parasites

The host may be said to have certain defenses against invasion by parasites and against those parasites that may succeed in gaining entrance. Among these may be mentioned:

a. Limitation of Avenues of Entrance.—Many parasites gain entrance into a new host only through the natural openings, the mouth (especially), the urogenital and respiratory openings. Others are introduced through the skin by biting animals which harbor the parasites, as indicated above. Although larval worms (e.g. hookworms) may bore directly through the skin of the definitive host, this method is uncommon among protozoan parasites of terrestrial animals but is employed by some protozoan parasites of aquatic hosts. Penetration of mucous membranes, however, is common among the trypanosomes (Figs. 44 and 45).

b. Secretion Products.—The digestive and other secretions may be harmful or lethal to unprotected parasites, especially the gastric juice with its hydrochloric acid and proteolytic

enzymes; and few protozoa succeed in remaining in the stomach of most animals more than a few hours without being killed. They may, however, live successfully in such modified portions of the œsophagus as the crop of birds (*Trichomonas columbæ*, Fig. 55) or the first and second stomachs of ruminants where an extensive protozoan fauna lives (see pp. 622–624). The small intestine with its rich supply of digestive juices harbors relatively few protozoa (species of *Giardia*, Fig. 50), while the caecum and colon, where stasis occurs and where digestive activity is reduced, are very commonly inhabited by intestinal protozoa.

c. *Serological Defenses.*—If a parasite invades the blood or other tissues its presence may call forth specific reactions on the part of the host resulting either in the parasite being made a more easy victim of phagocytes, or in preventing the multiplication of the parasite, or even injuring or killing the parasite (Taliaferro, 1929). (In addition to all these man uses heat, freezing, chemicals, etc., to sterilize food and drink.)

5. Variations in the Susceptibility of the Host and in the Virulence of the Parasite

Any evaluation of host-parasite relations must take into account not only the methods of invasion of hosts by the parasites and of the defenses of the host against invasion, but also the variability among individuals both in the susceptibility of the host and the powers of invasion by the parasite. Certain individuals, varieties or species of host may be immune to a particular species of parasite while their nearest relatives are not. It is well known, for example, that agricultural experts are continually seeking strains, varieties or species of domesticated plants and animals that may be naturally immune to this or that parasitic disease. Similarly, the parasite varies; the same strain or species may vary from time to time, depending upon the environment; or related strains, varieties or species may show persistent or constant differences in virulence. When these differences in susceptibility and in virulence are found to persist through succeeding

generations they may be thought of as genetic in character (Gowen, 1933), probably resulting from mutational changes.

6. *Effects of Parasitism upon the Parasite*

The assumption of the parasitic mode of existence is supposed to carry with it certain changes: (*a*) morphological, such as (i) simplification or loss of some of the structures possessed by the free-living ancestors (e.g., loss of mouth by astomatous ciliates, Figs. 5 and 6), (ii) the elaboration of other structures especially adapted to the changed mode of living (e.g., organelles for attachment to the host, Figs. 3, and 6); (*b*) physiological changes such as (i) enhanced powers of reproduction (multiple fission instead of binary fission, as in Coccidia (Fig. 4), (ii) behavior patterns which aid the parasites in colonizing themselves upon or within the host and in passing successfully from host to host (e.g., the trans-mittable gametocytes of certain hemosporidia develop in the circulating blood cells where they may be taken up by the biting vector while other stages develop in the internal organs), and (iii) the development of host specificity. (Examples are given in the next section.)

III. THE PROTOZOA AS PARASITES

Since the unicellular protozoa are regarded as the most primitive group of animals, from which the higher animals must have taken origin, they, more than any other phylum, have necessarily had a longer time in which to undergo their own evolution and in which to invade all possible environments. As a matter of fact, the protozoa have accomplished an extensive evolution below the level of multicellularity and have become widely distributed over the earth, living an active existence in practically all moist environments, including fresh water, salt water, moist soil and the bodies of most other animals and some plants.

1. *The Principal Groups of Protozoa*

The Phylum Protozoa may be divided into two subphyla and five classes, each class, except the Opalinata, including

several orders. An outline of the major groups with some indication of the development of parasitism among them is shown in table I. Two of the classes, the Sporozoa and the

TABLE I

Classes and Orders of Protozoa	Indication of Numbers of Parasites in the Group
Phylum PROTOZOA	
Subphylum PLASMODROMA	
Class MASTIGOPHORA	
Order Chrysomonadida	?
Order Cryptomonadida	few
Order Dinoflagellida	some
Order Phytomonadida	few
Order Euglenoidida	some
Order Protomonadida	many
Order Polymastigida	most
Order Hypermastigida	all
Class SARCODINA	
Order Proteomyxa	few
Order Mycetozoa	some
Order Foraminifera	?
Order Amœbæa	many
Order Testacea	few
Order Heliozoa	few
Order Radiolaria	?
Class SPOROZOA	
Subclass TELOSPORIDIA	
Order Coccidia	all
Order Hæmosporidia	all
Order Gregarinida	all
Subclass CNIDOSPORIDIA	
Order Myxosporidia	all
Order Microsporidia	all
Order Actinomyxidia	all
Order Helicosporidia	all
Subclass ACNIDOSPORIDIA	
Order Sarcosporidia	all
Order Haplosporidia	all
Subphylum CILIOPHORA	
Class OPALINATA	all
Class EUCILIATA	
Subclass CILIATA	
Order Holotrichida	
Suborder Astomina	all
Suborder Gymnostomina	many
Suborder Trichostomina	some
Order Heterotrichida	some
Order Oligotrichida	many
Order Hypotrichida	few
Order Peritrichida	many
Subclass SUCTORIA	many

Opalinata, contain only parasites and each of the other three classes, the Euciliata, Sarcodina and Mastigophora, includes species, genera, families or even suborders and orders of parasitic forms, along with those that are free-living.

2. The Sporozoa

The Class Sporozoa, all members of which are parasitic, is commonly divided into two or three sub-classes which differ so much from one another that it is difficult to decide whether one or more of the free-living classes may represent the ancestral groups. In this class we find many adaptive morphological and physiological features including the entire absence of oral apertures and, for the most part, the absence of the locomotor pseudopodia, flagella and cilia found in the free-living protozoa. We may, therefore, assume that a very long period of parasitism is represented and, consequently, we might expect to find a high degree of host specificity. Several monographic studies enable us to examine data bearing on this relationship.

a. *The Myxosporidia.*—The members of this group of highly evolved sporozoa (cf. Fig. 1) are found mostly in fishes where they dwell in various cavities and tissues such as the gall-bladder, the kidney tubules, the gills, muscles, etc. In his monograph on Myxosporidia, Kudo (1919) lists 237 species of which 213 apparently have known host relationships. Of these 213, each of 151 (70.9 per cent) is listed from a single species of host while each of 28 (13.1 per cent) is listed from two hosts and each of 34 (16 per cent) is recorded from three or more hosts.

Here, a majority of the species of Myxosporidia appear to be limited each to a single species of host and therefore rigid host specificity is indicated. There are, however, notable exceptions. Among those with three or more hosts we find *Chloromyxum leydigi* listed from twenty different hosts. Other species of *Chloromyxum* are reported from both the elasmobranchs and teleosts, and from fishes from both fresh water and marine sources, and have been reported from amphibia and even from an insect. In a recent paper Kudo

(1933) lists 23 species of the genus *Leptotheca*, 21 of which are found in marine fishes, usually in the gall bladder, while the other two species are found in the kidney tubules of amphibia. *Leptotheca ohlmacheri* (Fig. 1) has been found in frogs and toads in the United States by Kudo and others and the writer has observed it in the following anuran hosts: *Rana clamitans*, *R. pipiens*, *Bufo americana* and *B. valliceps*. Thus the principle of rigidity of host-parasite relations has many exceptions in this group of Myxosporidia, and doubtless further studies will reveal more of them.

  b. The Microsporidia.—The members of this order of Sporozoa are closely related to those of the Myxosporidia but the spores are characteristically smaller and somewhat simpler and the parasites are more widely distributed among the various phyla of animals, most being found in arthropod hosts.

  In Kudo's (1924) monograph on Microsporidia about 130 species have host relationships indicated. Of these, each of 95 (73 per cent) has been found in a single host, while each of twenty (15.4 per cent) is listed from two hosts and each of fifteen (11.6 per cent) is said to have three or more hosts. *Nosema apis* (Fig. 2), which attacks the cells lining the gut of the honey bee, is listed from this one host, yet Fantham and Porter (1914) state that this species may occur naturally in wasps and can be experimentally transferred to bumble bees, flies, sheep keds and certain kinds of butterflies and moths. Further experiments might reveal less host specificity than is indicated by the available records.

  The distribution of Microsporidia is surprisingly wide in contrast to the host limitations of the Myxosporidia. For example, species of the genus *Nosema* have been reported from hosts belonging to the protozoa, flat worms, bryozoa, round worms, annelids, and arthropods, the latter including certain crustacea and six orders of insects, as well as in fishes. Species of other genera are reported from rotifers. amphibia and reptiles. Thus many of the phyla of invertebrates and all the cold-blooded classes of vertebrates are reported as hosts of Microsporidia. Such a wide range of host relation-

ships as is recorded, especially for the genus *Nosema*, does not
indicate that evolution of species of parasite has been greatly
conditioned by the nature and evolution of the hosts.

    c. The Cephaline Gregarines.—The gregarines are relatively
large Sporozoa living primarily in the digestive tract, body
cavity and other organs of annelids and arthropods. The
cephaline gregarines, with attaching organelles, called epi-
merites, and with the body of each divided into two regions
by a septum (Fig. 3), are found mostly in the arthropods,
and the members of the simpler acephaline group are found
mostly in annelids.

    For the purposes of this discussion, reference will be made
to the monographs on cephaline gregarines by Watson (1916)
and Kamm (1922). In these monographs a total of 317
species (omitting some doubtful cases) are listed with their
host relationships. Of these, 269 (84.9 per cent) are indicated
as having each a single species of host and each of 35 (11
per cent) is listed from two hosts while each of thirteen
(4 per cent) is said to have been found in three or more hosts.
The high degree of host specificity recorded is accompanied
by the development of adaptive hold-fasts, the epimerites,
as noted above (see Fig. 3). However, attention may be
called to the fact that species of the genus *Gregarina* are listed
from five different orders of insects besides hosts among the
other classes of arthropods, the crustacea, the myriopods and
the arachnids, and, in addition, from other invertebrate phyla
including flatworms, annelids, rotifers, echinoderms, and
molluscs and the lower chordates, the tunicates and enterop-
neusta. Further, among the species listed from three or more
hosts, *Gregarina rigida* is recorded from twelve different
arthropod hosts. Also, it is not uncommon to find the same
species of host harboring a number of species of gregarines.
For example, Watson (1916) lists four species of the genus
Gregarina and one species of *Leidyana* from the cricket,
Gryllus abbreviatus. Thus while the gregarines are limited to
the invertebrates and lower chordates, and apparently show a
high degree of host specificity, yet there is a tendency for

some species to invade a number of different hosts and for different species to occur within the same species of host.

    d. The Coccidia.—Closely related to the gregarines are the Coccidia and we find the members of this order of Sporozoa distributed through most of the invertebrate phyla—including nemerteans, annelids (gephyreans, polychætes, oligochætes and leeches), all four classes of molluscs, and five classes of arthropods—the enteropneusta and all classes of true verte- brates where the number of species is very great.

    Within the group there are monotypic genera on the one hand and others which include large numbers of species. As an example of the former the genus *Wenyonella* may be mentioned with its single species, *W. africana*, thus far found only in a single reptilian host (Hoare, 1933), while *Eimeria* exemplifies a genus with numerous species.

    According to Levine and Becker (1933) the genus *Eimeria* has had 220 species recorded from 183 species of hosts in widely separated groups. These hosts include: annelids, 2 species; myriopods, 6 species; insects, 3 species; enteropneusta, 1 species; fishes, 43 species; amphibia, 10 species; reptiles, 26 species; birds, 24 species and mammals, 68 species. Not only are species of coccidia numerous in birds and mammals, but a single species of host may harbor several species of the same genus of parasite. According to Becker (1934) rabbits harbor five species of *Eimeria* and the domestic ox and the domestic chicken may each harbor six species of *Eimeria*. In each of these hosts the species are apparently closely related and at one time were considered single species. Evolution of new species within a single host is thus indicated. Although Andrews (1927), Tyzzer (1929) and Becker (1933a) have demonstrated host specificity to be rather rigid among the species of *Eimeria*, yet when we find these species ranging through all classes of vertebrates and into some of the inverte- brates, there seems to be little evidence of parallelism between the evolution of the parasites and of their hosts.

3. *The Ciliophora*

Metcalf (1923) and others have divided the Ciliophora into two general subgroups, the Opalinata, containing only the aberrant ciliates belonging to the Family Opalinidæ with undifferentiated nuclei, and the Euciliata, all of which have two types of nuclei. The Euciliata, in turn, are divided into the Ciliata proper, with cilia throughout active existence, and the Suctoria, which have sucking tentacles in the adult condition.

a. The Opalinidæ.—The members of this family are characterized by the absence of a mouth and by the presence of two or more similar nuclei in each animal. They are all endozoic, mostly in the large intestine of amphibia. Metcalf (1923) divides this family into four genera each containing from 30 to 40 species or subspecies. From the information given in Metcalf's monograph there appears to be a high degree of host specificity in this family. However, it may be noted that each of the four genera have species distributed through four families of anurans—Pelobatidæ, Bufonidæ, Hylidæ and Ranidæ—and two of them also have species in the tailed amphibia, indicating that speciation within the genus has not been limited to particular families of hosts. As to host specificity the data are, of course, incomplete, but Metcalf (1909) tried experimental cross-infections and as a result states: "It seems probable that any species of frog or toad can be infected with the cysts or adults of any species of *Opalina* (except, of course, *O. saturnalis*)." *O. saturnalis* was later called *Protoöpalina saturnalis* and occurs in the marine fish, *Box boöps* to which it is apparently specific.

The occurrence of an opalinid in a marine fish is not the only exception to their limitation to amphibian hosts. Lavier (1927) found a species of *Protoöpalina* in an African lizard, *Varanus niloticus*, and Carini (1933) has recorded a species of *Zelleriella* from a cobra, *Liophis jægeri*. Also, in the writer's laboratory a species of *Zelleriella* has been found in a tree boa from the West Indies. The species of *Zelleriella* from the tree boa appears to be identical with that (Fig. 5) found in

the southern tree frog, *Hyla cinerea*. These observations, together with the experimental transfers made by Metcalf (1909), indicate that host relationships may not be as specific among the opalinids as the results of examination of hosts to date would indicate. Metcalf (1928) later suggested that evolution of species among the Opalinidæ has taken place in a relatively constant environment and is due to internal causes, apparently involving orthogenesis.

b. Astomatous Ciliates in the Order Holotrichida.—In this as in other orders of the Euciliata, there is a differentiation between macronuclei and micronuclei. The members of the Suborder Astomina are all parasitic, without mouth openings and many of them have hooks (Fig. 6) or suckers by which they attach themselves to the digestive tract or other organ of their hosts. Probably a long period of parasitism is represented, yet they are distributed among many hosts (Cépède, 1910). Perhaps the majority have been found in annelids, but they have been recorded from cœlenterates, turbellarians, rotifers, bryozoa, echinoderms, molluscs and crustaceans among the invertebrates and from amphibians among the vertebrates. According to Cépède (1910) members of the genus *Anoplophrya* have been reported from bryozoa, molluscs and crustacea besides the three classes of annelids.

c. Amphileptus branchiarum.—Many ectozoic and endozoic ciliates are found among the members of the Holotrichida which possess mouths as do most ciliates. Among these, *Amphileptus branchiarum* (Fig. 7) which the writer discovered a few years ago on the gills of tadpoles (Wenrich, 1924b) is chosen as perhaps representing a transition between a predaceous status and a parasitic one. The other species of *Amphileptus* are commonly predaceous, frequently attacking and devouring vorticellas, trichodinas and other ciliates of the Order Peritrichida. *Amphileptus branchiarum* has a free-swimming stage during which it roams about over the gills of the host tadpoles and if, while doing so, it meets an ectozoic *Vorticella* or *Trichodina* it may indulge its predaceous tendencies by devouring one of them. At other times, and more

commonly, it attaches itself to the gills by a thin membrane within which it gently swims in a rotating manner, pausing at appropriate times to engulf masses of gill cells to satisfy its food requirements (Fig. 7). This species of *Amphileptus* is, perhaps, in the process of changing over from a strictly predaceous animal to one which may be regarded as definitely parasitic.

d. The Ciliates of Sea Urchins.—The ciliates living in the digestive tract of sea urchins provide us with some interesting data which may shed light upon the problem of the origin of the parasitic habit. From the recent papers by Lynch (1930), Biggar (1932), Powers (1933), Lucas (1934) and Uyemura (1934) we learn that ten or more genera of ciliates, most of them belonging to the Order Holotrichida, have thus far been described from this group of hosts and the urchins have been collected from such widely separated regions as the Mediterranean Sea, the North Sea, the coast of Maine and nearby regions, the coast of North Carolina, the Bermuda Islands, the Tortuga Islands, the coast of California and both the east and west coasts of Japan. *Cryptochilidium* (*Cryptochilum*), *Entorhipidium* and *Entodiscus* are genera so far not recognized in any other environments although they consist of species that are not greatly different from those of certain free-living genera. They have apparently undergone species evolution in the environment provided by the hosts, since Lynch described four species of *Entorhipidium*, for the one species of host, *Strongylocentrotus purpuratus* and Uyemura has described another species of *Entorhipidium* from two other species of *Strongylocentrotus* and from species belonging to three other genera of sea urchins. Thus in the genus *Entorhipidium* we have both the multiplication of species within a single species of host and also the spreading of another species into a number of different species of hosts. Besides these strictly endozoic genera there are representatives of the following genera, most of the species of which are free-living: *Plagiopyla, Colpidium, Colpoda, Uronema* and *Anophrys*, all belonging to the Holotrichida, and *Metopus*, belonging to the

Heterotrichida. Kahl (1932) recognizes more than 50 free-living species of *Metopus*, most of them from fresh water but a few from marine or brackish water. A number of species of this genus have been found in sea urchins and in this as well as in the other genera just mentioned, there is apparently an adoption of the endozoic habit with but little change in the characters of the animals that have thus transferred from a free-living existence. Some of the species of these genera may prove to be facultative, but others are apparently unable to live very long in sea water, the environment of the host. This situation apparently illustrates the circumstance that, when free-living protozoa first become endozoic they do not necessarily undergo any marked morphological modification. When the association persists over long periods of time, divergent evolutionary processes may result in the development of forms which can no longer be placed in the same genus as their near relatives among the free-living animals.

e. *The Genus Nyctotherus.*—Somewhat related to *Metopus* is the genus *Nyctotherus* (Fig. 8), all species of which are endozoic in various animal hosts. Although four doubtful species of the genus have been described from warm-blooded hosts, one from the guinea pig and three from man, the other species so far described have been limited to cold-blooded vertebrates and to invertebrates. Most of the vertebrate hosts of *Nyctotherus* are amphibians, especially frogs, toads and tree frogs, but species have been described from fishes and reptiles. Among the invertebrate hosts are oligochæte worms, crustaceans, myriopods, a variety of insects, such as cockroaches, mole crickets, beetle larvæ, crane-fly larvæ, and termites; also echinoderms and molluscs. Not only are the species of this genus widely distributed among cold-blooded hosts, but the same species may live in a number of different kinds of host and the same species of host may harbor a number of different species of *Nyctotherus*. For example, *Nyctotherus cordiformis* has been recorded from a variety of frog and toad hosts from all the continents, and *Rana tigrina* and *Bufo marina* are each recorded as harboring two or more

species of *Nyctotherus*. Thus the distribution of the species of the genus *Nyctotherus* appears to bear little relation to the systematic relations of the host.

f. The Genus Balantidium.—Another genus of parasitic ciliates belonging to the Order Heterotrichida is *Balantidium* (Fig. 9), with species scattered through the animal kingdom. According to recent papers by Bhatia and Gulati (1927) and by Hegner (1934a) about 50 species of this genus have been described with more from mammals and amphibia than from any other major groups of hosts. Birds, reptiles and fishes also harbor certain species and among the invertebrates recorded as hosts are coelenterates, flat worms, annelids, molluscs, crustacea and insects. Here, again, we have records of species which may inhabit several kinds of hosts and certain hosts that may harbor several species of this genus of parasites. *Balantidium coli*, which is occasionally found in man in various parts of the world, is apparently also found in other higher primates and in the domestic pig. Schumaker (1930) was able to transfer this species from pigs to guinea pigs and still more successfully to rats. From the criteria provided by Hegner (1934a) it appears that the chimpanzee may harbor another species (Fig. 9) in addition to *B. coli*. *Balantidium duodeni*, *B. elongatum* and *B. helenæ* have each been recorded from as many as four different species of amphibian hosts and *Rana tigrina* has been recorded as harboring as many as six species of *Balantidium*. It may be that not all of these six are distinct species, but other kinds of amphibia also harbor several species of *Balantidium*. Thus, evolution of species in the genus *Balantidium* appears to be to a considerable extent independent of the evolution of the hosts.

g. The Ophryoscolecidæ and Cycloposthiidæ.—In the ciliate Order Oligotrichida, are certain families that have undergone extensive evolution in certain groups of hosts. The members of the Family Ophryoscolecidæ (cf. Fig. 10) are found primarily in the first and second stomachs of ruminants. Related families are found in the caeca of the Equidæ and their

relatives and also in some rodents and higher primates (Gorilla and Chimpanzee).

In recent studies by Kofoid and MacLennan (1933) on the ciliates of the stomach of the Indian humped ox, *Bos indicus*, 100 species belonging to thirteen genera are recorded from this one species of host. It is noteworthy that the genus *Ostracodinium* is represented by 19 species, *Entodinium* by 20 species and *Diplodinium* by 23 species. One host individual harbored fifteen species of *Entodinium*.

Considering the Family Ophryoscolecidæ still further, a survey of papers by Buisson (1923), Dogiel (1927), Becker and Talbot (1927) and Hsiung (1931, 1932) indicates that other ruminants have numerous species belonging to this family. Thus, domestic cattle are credited with 107 species included in seven genera, the domestic sheep with 37 species in four genera, the reindeer with seventeen species in three genera and the dromedary with nine species in seven genera. Other ruminants, such as camels, antelopes, etc., all have their members of this family of ciliates, but have not been fully investigated. Many of these ophryoscolecids occur in several species of hosts, for example, *Entodinium longinucleatum* has been reported from the Indian ox, domestic cattle, Chinese cattle, Chinese sheep, reindeer and dromedary; and *Eudiplodinium maggii* is recorded from domestic cattle in various parts of the world, from the Indian ox and from five different genera of African antelope. There is thus a striking tendency toward evolution of species in this family of ciliates within the group of hosts known as ruminants and also within single host species, and host specificity is not very rigid. Crawley (1923) has pointed out that in the Ophryoscolecidæ the characters represented by the cilia vary independently of those represented by the form and arrangement of the armature of spines and skeletal structures. This suggests a mutational origin of such variations in either set of structures independent of the other.

It is also to be noted that the first and second stomachs of the ruminants harbor many other protozoa belonging not

only to other groups of ciliates but also to the flagellates and amœbæ.

The Family Cycloposthiïdæ (cf. Fig. 11) is closely related to the Ophryoscolecidæ, just mentioned, but its members are found primarily in the cæcum of members of the equidæ, especially the domestic horse. From this one host, Hsiung (1930) lists nineteen species included in seven genera of this family with nine species in the one genus, *Cycloposthium*, so that extensive evolution of species is indicated for this ciliate family in a single species of host. There are a considerable number of other ciliates belonging to other families and orders in the equidæ and similar ciliates are found in the tapir, elephant and rhinoceros (Buisson, 1923). In addition to the nineteen species of Cycloposthiïdæ, Hsiung lists from the horse 33 other species of infusoria including seventeen species of twelve genera of the holotrichous family Bütschliïdæ and three species of a suctorian, *Allantosoma*, besides two species of *Endamœba* and four kinds of flagellates, including a *Trichomonas*.

It is also interesting that several species of *Cycloposthium* (Fig. 11) along with other ciliates much like those of the horse, occur in the cæcum of the large rodent, *Hydrochœrus capybara* of South and Central America (Cunha and Muniz, 1927). One hesitates to suggest that a taxonomic relationship between the horse and the rodent is indicated by the similarity of their cæcal protozoa, yet the horse is supposed to have evolved from a rodent-like ancestor on the American continents. At any rate, the Ophryoscolecidæ and Cycloposthiïdæ illustrate a capacity for extensive evolution of species within limited groups of hosts.

4. The Sarcodina

Representing the Class Sarcodina, there is an extensive series of endozoic amœbæ. The amœbæ are usually considered to be the simplest animals yet they are highly successful in maintaining themselves, both as free-living organisms and as parasites. We may well refer to those found in man

and their nearest relatives found in other animals. In man as many as six species of endozoic amœbæ are recognized belonging to the genera, *Endolimax, Dientamœba, Iodamœba* and *Endamœba*.

Man harbors *Endolimax nana* (Fig. 12) and apparently the same species occurs also in other higher primates (Dobell, 1933, Hegner, 1934b). Very similar forms are found in other mammals (e.g., guinea pig, Fig. 13), and various birds, lizards, frogs (Fig. 14), and rock fish, among the vertebrates; and a considerable number of invertebrates including cockroaches (Fig. 15), millipeds (Fig. 16), crane-fly larvæ (Fig. 17), Japanese beetle larvæ (Fig. 18), and leeches. Examination of specimens from such a series of hosts (Figs. 12 to 18) will indicate how difficult it is to recognize species by morphological characters alone. Experimental transfers may help to determine species limits. Dobell (1933) has demonstrated that the *Endolimax* of rhesus monkeys can be transferred to man but he could not colonize it in cats. On the other hand, Kessel reported successful transfer of *Endolimax* from man to rats (1923) and domestic pig (1928a) as well as to the monkey (1928b), and Chiang (1925) and Smith (1928) reported the natural occurrence in rats of an *Endolimax* similar to *E. nana* of man.

The species of *Endolimax* resemble very closely many of the small free-living limax amœbæ so that, apparently, the endozoic habit has been adopted with very little morphological change, and the endozoic group has invaded an extensive series of animal hosts belonging to various phyla with little evidence of morphological evolution. If it is found by appropriate experiments that many of these show rigidity of host-parasite relations, one may be justified in referring to them as physiological species.

The genus *Dientamœba* is thus far represented by only one species, *D. fragilis* (Figs. 19 and 20), found originally in man. Recently, however, Hegner and Chu (1930) have discovered what appears to be the same species (Fig. 20) in wild monkeys in the Philippines and Regandanz (1929) has reported its

successful transfer to rats. With the normal hosts of this amœba apparently limited to man and monkeys, the evolutionary history of the species presents an interesting problem. Presumably it has either evolved from other species residing in its present hosts or it has been derived from some other, as yet unrecognized, reservoir host among other animals, or more directly from a free-living ancestor.

The genus *Iodamœba*, represented by *I. bütschlii* was also first recognized as a parasite of man (Figs. 21 and 22) but this species has its counterpart in monkeys and apes (Figs. 23 and 24). Although Kessel (1923) and Smith (1928) reported its successful transfer to rats, until recently the domestic pig was the only other animal known to harbor natural infestations of *Iodamœba*. Now, Fantham (1932) has reported a species from a tortoise in Africa, and doubtless other hosts will be discovered. There are no obvious specific differences between the strains of *Iodamœba* from man, apes, monkeys and pigs, but actual host-parasite relations must await more experimental data.

Man harbors three or more species of the genus *Endamœba*, one in the mouth (*E. gingivalis*) and the others in the large intestine. Amœbæ apparently identical with *E. gingivalis* have been reported from the mouths of other animals including dogs and cats (Goodrich and Mosely, 1916), horses (Nieschulz, 1924) and monkeys (Hegner and Chu, 1930).

The two common species of *Endamœba* in the large intestine of man are (1) *E. histolytica* (Figs. 25 and 26) which may invade the tissues causing intestinal ulcers, amœbic dysentery or amœbic abscesses in the liver and other organs, and (2) *E. coli* (Figs. 37 and 38) which is apparently harmless. Other species of *Endamœba* occur in all classes of vertebrates and in many invertebrates including such animals as the cockroach (Figs. 33 and 34), crane fly larvæ (Fig. 35) and Japanese beetle larvæ (Fig. 36).

Endamœba histolytica and *E. coli* of the large intestine of man are apparently duplicated in the apes and monkeys, but forms which are almost as difficult to distinguish, on morpho-

logical grounds, are found in other animals, such as rats and frogs. Furthermore, there is greater similarity between *E. ranarum* (Figs. 29 and 30) and *E. histolytica* (Figs. 25 and 26) than between the latter and *E. coli* (Figs. 37 and 38) which lives with *E. histolytica* in the human colon. One of the amœbæ of the rat (Figs. 27 and 28) resembles *E. histolytica* of man more than it does the other one of the rat (Figs. 39 and 40) which in turn more nearly resembles *E. coli* of man. *E. histolytica* has been successfully transferred from man to such animals as monkeys, dogs, rabbits, guinea pigs, pigs and rats. Also spontaneous infections with what appeared to be this species have been reported for monkeys (Hegner and Chu, 1930), cats (Kessel, 1928), dogs (Andrews, 1932) and rats (Lynch, 1915; Brug, 1919; Chiang, 1925 and Smith, 1928). Ratcliffe and Geiman (1934) have found an amœba in snakes which greatly resembles *E. histolytica* both in its morphology and its capacity to invade tissues, causing intestinal ulcers and liver abscesses. Host specificity is obviously not very rigid in the case of *E. histolytica* and the species relations within the genus show little parallelism with the taxonomy of the hosts.

5. *The Mastigophora*

Many authorities regard the Mastigophora, some of which have chlorophyll in their bodies, as the most primitive group of protozoa from which all the other major groups (and perhaps also the higher plants and higher animals) have been derived, either directly or indirectly.

a. Endozoic Euglenoid Flagellates.—The Order Euglenoidida includes many kinds with green chlorophyll and some without chlorophyll. Some of both these categories have taken up residence within animal hosts. *Euglenamorpha hegneri* (Fig. 41) is found in the large intestines of the tadpoles of many species of frogs and toads (Wenrich, 1924a). Because it possesses green chlorophyll like its free-living relatives, one may presume that it has only recently evolved from free-living ancestors, or else evolution was arrested after the endozoic habit was assumed. However, along with this

green species, one often finds a colorless variety, *E. pellucida* (Fig. 43), and the presence of intermediate forms (Fig. 42) suggests that specimens of *E. pellucida* may be modified individuals of the green species. On the other hand, one often finds tadpoles that harbor only the colorless form and in a few instances the writer has found the colorless variety in the urinary bladder of recently metamorphosed frogs (*Rana pipiens*, collected at Lawrence, Kansas). Here we seem to have a picture of evolution in progress. *Euglenamorpha hegneri* is like free-living euglenas except that it has three flagella while the free-living species have only one (genus *Euglena*) or two (genus *Eutreptia*). *Euglenamorpha pellucida* has from three to six flagella and *Hegneria leptodactyli*, another colorless euglenoid reported from tadpoles in Brazil by Brumpt and Lavier (1924), is said to have seven flagella.

With these and other examples, to be mentioned below, the two phases of evolution, the morphological and the physiological, may be illustrated. A few years ago the writer chanced to examine a large milliped (*Spirobolus marginatus*), which had been kept for some time in an aquarium jar containing damp sphagnum. It was surprising to find, in the intestine of this animal, considerable number of a species of colorless euglenoid belonging to the genus *Menoidium*. These flagellates were apparently living a contented existence in this endozoic habitat and they were also found free-living in the moist sphagnum. This free-living flagellate thus displayed the facultative capacity of maintaining for a brief time, at least, an endozoic existence. Since Hegner (1923) had shown that different species of euglenoids differ notably in their susceptibility to digestion in the digestive tract of tadpoles, the writer, with the help of Miss Marian Savin, conducted experiments to try to infect individuals of *Spirobolus* with *Euglena gracilis*. It was found that when this species of *Euglena* was fed to the millipeds, some of the flagellates were killed and partly digested, some were killed but not digested, and some were not killed. Active euglenas

could be recovered by killing the milliped and examining the contents of its intestine a day or two after feeding, and could be recovered from the feces of the millipeds fed with euglenas. However, the sojourn of the euglenas in the milliped was very limited. We may say, then, that *Menoidium sp.* and *Euglena gracilis*, to a less degree, were capable of surviving in the intestine of the milliped for a matter of a few days but were unable to colonize themselves as endozoic flagellates. On the other hand, colorless euglenas (*Euglena leucops* and other species) have become definitely parasitic in the digestive tract and tissues of certain rhabdocœle worms (Hall, 1931). Since there are free-living as well as parasitic euglenas, which are colorless, it cannot be determined whether or not the colorless feature of the endozoic species became manifest after the parasitic mode of existence was assumed. *Euglena-morpha hegneri* has become adapted to an endozoic existence (no free-living species of *Euglenamorpha* are known) but it retains its chlorophyll while adding one or two flagella. *E. pellucida* living in the same environment as *E. hegneri*, has undergone more marked morphological changes, losing its chlorophyll and increasing the number of flagella up to six, and *Hegneria leptodactyli* has seven flagella. In certain cases *E. pellucida* has taken an additional physiological step by invading the urinary bladder of transforming tadpoles and has persisted for a time in young frogs, but no further morphological changes could be noted. Thus in the *Euglena* group, a definite parasitic habit has been accompanied by little morphological change, other than the loss of chlorophyll, while in the *Euglenamorpha* group, apparently, marked morphological changes have resulted from the assumption of an endozoic existence.

b. The Hæmoflagellates.—The family Trypanosomatidæ consists of five or six closely related genera containing species which inhabit a wide range of hosts from latex-bearing plants up to man. The species of the genus *Trypanosoma* (Figs. 44 and 45) are found as blood-inhabiting parasites in all groups of vertebrates and in certain transmitting hosts such as

leeches, biting insects and in one case, a mammal, the blood-sucking bat of Central America. Wenyon (1926) gives a list of nearly 500 species of vertebrates in which one or more species of *Trypanosoma* live naturally or have been introduced experimentally. This list of hosts includes 119 kinds of mammals, 206 kinds of birds, 33 of reptiles, 37 of amphibia and 102 of fishes. Calkins (1933) gives a list of trypanosomes that have been described from vertebrate hosts and this list is distributed as follows: 93 species in mammals, 148 in birds, 29 in reptiles, 41 in amphibia and 93 in fishes. As Calkins suggests, it is probable that many of these are not distinct species, but the two lists serve to give an idea of the widespread distribution of the members of the genus *Trypanosoma* through all the major groups of vertebrates.

Within the genus *Trypanosoma* some species show rigid host specificity while others show very little specificity. Experimentally, a number of species of *Trypanosoma* have been transferred to an extended series of laboratory animals, indicating a lack of host specificity and, on the other hand, the same host may harbor a number of species of the same genus. Even man harbors two and possibly more species and recently *Trypanosoma lewisi*, which is supposed to be specific for rats, has been reported from the blood of a human being (Johnson, 1933). Not only have the members of the genus *Trypanosoma* undergone an extensive physiological evolution, as represented by their capacity to live in so many different kinds of hosts, but they have also undergone a morphological evolution. There are many specific morphological characters including great range in dimensions and internal structure (compare Figs. 44 and 45). Space does not permit more extended discussion of this interesting group of hæmoflagellates, but the evidence indicates that evolution of species exhibits little parallelism with the evolution of the hosts.

Other genera of the Family Trypanosomatidæ are *Crithidia, Herpetomonas* and *Leishmania*. Species of *Crithidia* are limited to the digestive tract of invertebrates where, according to Nöller (1931), they are found in many families of the

insect Orders, Hemiptera and Diptera, and also in fleas, bees and ticks. According to Nöller (1931) species of *Herpetomonas* (including his subgenus *Leptomonas*) (Fig. 47) have been reported from a large number of insect hosts and also from ticks, wasps, nematodes and molluscs among the invertebrates and from all classes of vertebrates. Experimental evidence indicates that the same species of *Herpetomonas* may be transferred to many different species of host (Becker, 1923). Another group of species, sometimes placed in a separate genus, *Phytomonas*, is found in certain latex-bearing plants (Fig. 46) and they are transmitted from plant to plant by juice-sucking bugs. Species limits in this group have not been satisfactorily determined, although host specificity is apparently not very rigid (Holmes, 1930). Species of the genus *Leishmania* have an aflagellate phase (Fig. 49) in the body cells of some vertebrates and a flagellate phase (Fig. 48) in the digestive tracts of insects and in culture. While the species of this genus seem to have a limited distribution among animal hosts, it is interesting that two or three species have been recognized in man and apparently the same species occur in dogs. They are also transmittable to monkeys and to a variety of rodents. Still other species occur in lizards (see Wenyon, 1926). Host specificity does not seem to be very rigid for the species of *Leishmania*.

Considering the Trypanosomatidæ as a whole, we have the simplest species in the genera *Leishmania* and *Herpetomonas* (including *Leptomonas* and *Phytomonas*) which are found in a wide variety of hosts from plants up to man, and which are closely related, morphologically, to some of the simpler free-living flagellates. Species of *Crithidia* are somewhat more complex with a slightly developed undulating membrane and are limited to invertebrate hosts. *Trypanosoma*, with its highly developed undulating membrane (Figs. 44 and 45), is found in all groups of vertebrates and in those invertebrates which act as transmitting agents.

c. The Polymastigida.—The polymastigote flagellates are more complex than the hæmoflagellates in that they have

from two to eight flagella (more in the polymeric Poly-monadina) and usually possess a mouth and a variety of fibrils or rods such as axostyles, parabasal bodies, etc., and may also have an undulating membrane with supporting rods. Most of them are parasites.

The trichomonad flagellates have several flagella, an axo-style and an undulating membrane with one or more accessory fibrillar structures (Figs. 51 and 53–66). Several species of *Trichomonas* have been described from man and others are found in animals belonging to all the classes of vertebrates and in some invertebrates. A few are selected for discussion.

Trichomonas elongata (Fig. 53) of the human mouth and *T. vaginalis* (Fig. 54) of the urinogenital tract are closely related, morphologically, and may possibly be the same species. Forms similar to these vaginal trichomonads have been found in monkeys, and forms similar to *T. elongata* have been found in the mouths of dogs and horses as well as of higher primates. A species very similar in morphology to *T. vaginalis* is *T. columbæ* (Fig. 55) found in the crop of pigeons and doves (Oguma, 1931). *Trichomonas hominis* (Fig. 56), the more common species in the intestine of man, is indistinguishable morphologically from trichomonads from the intestines of rats (Fig. 57), monkeys (Fig. 58), cats and dogs. On the basis of the morphological studies of Wenrich (1931) and others and the experimental work of Wenrich and Yanoff (1927), Kessel (1928b), and Simić (1933) it seems probable that the one species may live in all of these hosts, and Hegner (1929) was able to transfer it from man to chicks where it remained as long as 141 days. The second species from the intestine of man, *T. fecalis* (Fig. 59), has a close counterpart in *T. batrachorum* (Fig. 60) from the intestine of frogs and toads. and, morphologically, they are indistinguish-able. A species from the genital tract of cows (*T. fœtus*, Fig. 64) instead of resembling the one from the human genital tract (Fig. 54), is more like a species from the intestine of monkeys (Fig. 63), and the latter species is more like *T. muris* of rats (Fig. 62), *T. caviæ* of guinea pigs (Fig. 65) and *T.*

augusta of frogs (Fig. 66) than it is like any species found in man.

Alexeieff and Gwéléssiany (1929) state that in Europe *Trichomonas augusta* (Fig. 66) occurs only in toads and not in frogs. On the contrary, in the writer's experience this species, although varying somewhat in size in different infections, occurs in a large number of amphibian hosts including some tailed amphibia as well as frogs and toads. For example, in: (*a*) Anura: *Rana clamitans*, *R. catesbiana*, *R. pipiens*, *R. palustris*, *R. aurora draytoni*, *Pleurodema bibroni* (Chile), *Acris gryllus*, *Hyla pickeringi*, *H. versicolor*, *H. cinerea*, *Bufo americana*, *B. cognatus*, *B. valliceps*, *B. marina* (Panama, Island of Trinidad), *B. spinulosis* (Chile), *Gastrophryne texensis*, *Schaphiopus hammondi*, *Calyptocephala gayi* (Chile); (*b*) Urodela: *Cryptobranchus alleghaniensis*, *Triturus viridescens*, *Desmognathus fuscus* and *Pseudotriton ruber*.

Thus, in the trichomonad group of flagellates, morphological speciation has cut across the taxonomic lines of the hosts giving little evidence of parallelism between the classification of the parasites and that of the hosts.

Within the limited host environment represented by certain genera and families of termites, the polymastigote flagellates have undergone an extensive evolution producing larger and more varied species than are found in other host groups so far studied, with the exception of the wood-eating roaches (cf. Fig. 51). Not only have they evolved into many genera and species of single units, but they have undergone polymerization, with varying multiples of the fundamental unit represented by a single trichomonad. Kirby (1930) lists five families and twenty genera of monomonad polymastigotes and one family with five genera of polymonad forms.

This extensive evolution within a limited host association is paralleled by the flagellate Order, Hypermastigida, the members of which are confined to two groups of insects, the termites and the roaches. Within these host groups an amazing development of families, genera and species has taken

place producing the most complex flagellates known to zoölogists (cf. Fig. 52). From the termites Kirby (1930) lists seventeen genera separated into ten families. Cleveland and associates (1934) have found a series of flagellates living in the intestine of the wood-eating roach, *Crytocercus punctulatus*, which rivals that of the termites. They include twenty species of hypermastigotes in nine genera in addition to five species of polymastigotes in three genera. Thus in this single species of host an extensive evolution of flagellate species, especially of the hypermastigote type, has taken place.

Among the polymastigote flagellates belonging to the Sub Order Diplomonadina, there are two genera, *Giardia* (Fig. 50) and *Hexamita* (Figs. 67–86), each of which has undergone extensive evolution into species and has developed wide host associations. Although limited to the vertebrates the species of *Giardia* are found in all the classes from fishes to mammals. According to Hegner (1930) and others there seems to be a rather rigid host specificity in this genus, yet Hegner (1927) succeeded in transferring *Giardias* from man to rats and obtained evidence (confirmed by Potter, 1927) that *G. lamblia* of man may live naturally in rats, along with another species, *Giardia muris* (Fig. 50). The restricted host relationships among the species of *Giardia* even with the exception just noted, is quite in contrast to the situation in the genus *Hexamita* which will next be considered.

The genus *Hexamita* is interesting because its species range more widely in their environmental relationships than any of the generic groups heretofore mentioned. Species of *Hexamita* occur free-living in both fresh and salt water and as ectozoic and endozoic associates of aquatic invertebrates and vertebrates living in both fresh and salt water, and also endozoically in terrestrial vertebrates and invertebrates. A few of these are represented by Figs. 67 to 86. If we try to select the species that are most alike morphologically, we find that they have no parallel relation to the taxonomic relationships of the hosts. There is almost as much range of morphology among free-living freshwater species (Figs. 84–86)

as there is among the parasitic ones (Figs. 67–83). Among
the latter we may find several distinctive types of morphology
in the same species of frog, for example, in *Rana pipiens*
(Figs. 67, 72, 77, 80) and even in the same individual frog at
different times. The species from the monkey (Fig. 79) most
nearly resembles certain ones from frogs and turtles (Figs. 77,
78). In rats and mice there is one species in the cæcum
(Fig. 82) and another in the small intestine (Fig. 83). The
one in the cæcum, instead of showing resemblance to the one
in the small intestine of the same host, more nearly resembles
certain species in frogs, toads and salamanders (Figs. 80 and
81). A species found on the outside of a marine fish (Fig. 73)
more nearly resembles one from a milliped (Fig. 74) than it
does the one from the inside of another marine fish (Fig. 69).
Altogether, there is very little parallelism between the
morphology of the endozoic species of *Hexamita* and the
taxonomy of their hosts.

6. Host Tolerance for Different Types of Parasites

As previously noted there are frequent examples of single
species of parasite or of the species of a single genus invading
a number of different hosts. Also the same kind of host may
harbor a number of species belonging to the same genus of
parasite. Furthermore, the same species of host often harbors
parasites representing widely different major groups of
Protozoa. If the host, as representing a special and limited
environment, were to produce any marked directive influence
upon the evolution of species of parasite, then there should
be more evidence of convergence in evolutionary trends in
different groups of parasites than we actually find.

Attention has already been called to the fact that rumi-
nants not only harbor a surprisingly large number of species
of ciliates belonging to the Family Ophryoscolecidæ, but also
ciliates belonging to other families and orders besides amœbæ
and flagellates. Similarly, in the horse, in addition to
numerous species and genera belonging to the oligotrichous
family, Cycloposthiidæ, and the holotrichous family, Bütsch-

liidæ, there are many other kinds of ciliates, and several species belonging to the Suctoria, besides amœbæ and flagellates. Man is known to harbor some 25 or more different species of protozoa (Hegner, 1928) representing all classes, including about fourteen species of Mastigophora, six or more species of Sarcodina, four or more species of Sporozoa and one or more species of Ciliata, besides various metazoan parasites.

In this connection it may be of interest to list the series of protozoan parasites that the writer has observed associated with a single species of frog, such as *Rana clamitans*, or *R. pipiens*. In addition to *Trypanosoma* (Mastigophora, Protomonadida) and *Hæmogregarina* (Sporozoa, Coccidia) in the blood and *Leptotheca* (Sporozoa, Myxosporidia) in the tubules of the kidney, the following have been found in the large intestine of adults: Class Mastigophora, Order Protomonadida, *Rhizomastix;* Order Polymastigida, *Retortamonas, Chilomastix, Trimitus, Karotomorpha, Monocercomonas, Monocercomonoides, Hexamastix, Trichomonas* (two species), *Trepomonas, Hexamita* (three or more species); Class Sarcodina, Order Amœbæa, *Endamœba, Endolimax;* Class Opalinata, *Opalina;* Class Euciliata, *Nyctotherus.* In the small intestine one finds one or more species of *Eimeria* (Sporozoa, Coccidia). In the large intestine of tadpoles one also finds *Euglenamorpha* (Mastigophora, Euglenoidida) and in the small intestine, *Giardia* (Mastigophora, Polymastigida). And to make the list more complete we may note that on the outside of tadpoles (Wenrich, 1924c) the following have been found: Class Mastigophora, Order Polymastigida, *Costia;* Class Euciliata, Order Holotrichida, *Amphileptus;* Order Peritrichida, *Trichodina, Scyphidia, Glossatella, Rhabdostyla, Opercularia* and *Vorticella.*

In some of these genera there are several species, often found living together without any obvious antagonism. The phenomenon of a single species of host harboring so many different kinds of parasites does not suggest that the host, as

a specific type of environment, has had a directive influence on the evolution of the parasites.

IV. Discussion

1. Origin of the Associated Habit

It seems obvious that associated protozoa have developed from free-living ancestors. On the other hand, there is not much evidence that endozoic species have developed from ectozoic ones, as has been suggested by various authors. As noted by Reynolds (1930) for example, these ectozoic forms are mostly primitive flagellates, peritrichous ciliates or suctoria. Only a few genera, for example, *Trichodina* and *Hexamita*, contain both ectozoic and endozoic species. It seems more probable that the endozoic habit began, in most cases, with an adaptation to life in the digestive tract of the host; from there the parasites have spread to the blood and other tissues and organs. When one considers the vast numbers of free-living protozoa that must be taken in daily by higher animals with their food and drink, it is perhaps surprising that more of them have not been able to adapt themselves to an endozoic habitat.

How does a free-living animal adapt itself to live within a host? If it succeeds in surviving in the new environment, we must assume either that it already possessed the physiological properties which enabled it to cope with the new conditions, that is to say that it exhibits preadaptation (see Goldschmidt, 1933), or else it would have to acquire such properties at the time that it was taken in. It is, of course, recognized that hosts vary within the species as to their resistance or tolerance to invasion and that the same individual host may vary from time to time in its powers of resistance. Adaptation to an endozoic existence involves more than the ability to withstand the digestive and other secretions of the host. The parasite must be able to nourish itself, grow, and multiply in the host and then it must succeed in getting transferred to other hosts, either of the same or other tolerant

species. The invasion of a new host may be coincident with some genetic change in either the host or the parasite which makes possible the new association. One wonders to what extent the successful invasion of an original host or the successful transfer to a new species of host must await such a conjunction of favorable mutations and the accident of being taken into a host.

The associated habit, once established, the spread from host to host reflects the principle of opportunism, just as does the geographic dispersal of most animals. Any species of parasite will, presumably, establish itself upon or within any kind of host in association with which it finds favorable conditions for survival.

2. Host Specificity

There is no question as to the existence of a greater or less degree of rigidity in host-parasite relations, just as there are many free-living animals with highly limited habitats. The writer can go to his front lawn in the spring and pull up a dandelion plant on the roots of which there will be a quantity of soil; in this soil may be found an earthworm and a Japanese beetle larva. If the intestines of these two animals be examined, it will be found that both contain a good deal of soil but mixed with the soil and intestinal fluid may be found a number of endozoic protozoa. However, in the earthworm there will commonly be found only ciliates; such as *Plagiotoma*, which is limited to earthworms, and astomatous forms such as *Hoplitophrya* (Fig. 6), also limited to annelids. On the other hand, in the intestine of the beetle larva, one may find, not ciliates, but amœbæ and flagellates. The amœbæ belong to the genera *Endamœba* and *Endolimax*, which have species in many other groups of hosts, including man. Among the flagellates are species of *Polymastix*, *Monocercomonas*, *Monocercomonoides* and *Retortamonas*. The genus *Polymastix*, is limited almost entirely to insect hosts, while the other genera have species in many hosts, both vertebrates and invertebrates. The earthworm and beetle larva have obviously

ingested samples of the same soil, yet each derives a totally different protozoan fauna therefrom. Thus the principle of limitation of host relations is exemplified.

Host specificity may be thought of as primarily physiological in nature, since it represents an adaptive capacity of each species of parasite to maintain itself in the peculiar chemical and physical conditions provided by its own particular species of host and an inability to reach or to maintain itself in environments provided by other species of possible hosts. Fundamentally all physiological characteristics are contingent upon the structural make-up of the individual, and hence adaptation must include morphological as well as physiological aspects. However, among simpler parasites, such as *Endolimax* (Figs. 12–18), physiological differences, in the nature of specificity for different kinds of hosts, may exist without recognizable morphological distinctions. In such cases we may think of physiological varieties or species.

For one species to be differentiated from another, however, it is necessary for each to have persistent hereditary characters not possessed by the others. The physiological differences of physiological species must be hereditarily stable and may be the result of physiological mutations unaccompanied by visible morphological changes. On the other hand, when morphologically different species occur in the same host, they must have some adaptive physiological characters in common, although they may differ in other respects, such as food habits. Thus *Trichomonas batrachorum* (Fig. 60) and *T. augusta* (Fig. 66) live side by side in the rectum of a frog or other amphibian, yet they have distinctly different food habits and they are strikingly different in morphology. Since the same species of frog may harbor in its digestive tract species belonging to a dozen different genera of flagellates, two genera of amœbæ and two or more genera of ciliates, it seems obvious that host specificity and speciation are not necessarily parallel (cf. Becker, 1933b).

3. Origin of Adaptive Structures

Some biologists find it difficult to account for adaptive structures upon the basis of the principles of mutation and natural selection, preferring a Lamarckian interpretation for the origin of such structures. How, for example, did the gregarine, *Actinocephalus* (Fig. 3) and the ciliate, *Hoplitophrya* (Fig. 6), get the hooks by means of which they attach themselves to their hosts? In the life history of the cephaline gregarines, most of them enter the digestive tract of a new host as spores within which are minute spindle-shaped sporozoites. These sporozoites emerge and penetrate into cells of the host without any spines or hooks or other evidence of attaching structures. As they grow to be too large to be accommodated in the host cells, they protrude into the cavity and develop the epimerites or hold-fasts. But there are many different kinds of hold-fasts, the various families, genera and species being differentiated from each other, in part, at least, by the character of this structure. Some of these epimerites are simple knobs that appear to be just as useful to their possessors as are the very elaborate ones possessed by others. Furthermore, many gregarines, especially the non-septate forms, have no epimerites, yet are highly successful in maintaining themselves. With regard to *Hoplitophrya*, it is interesting that species of the related genus, *Anoplophrya*, also living in the intestines of earthworms, have no hooks at all, yet they appear to be equally successful in surviving. It therefore appears that, while many of these apparently adaptational structures would seem to be highly useful to the animals that possess them, nearly related forms can get along without them. Such specialized structures as hooks for attachment to a host were probably not present in the ancestral forms which succeeded in entering and maintaining themselves in a host. They are the products of evolutionary change. Are they, then, produced by the effects of use and disuse, or of the needs of the parasites, or are they the result of mutational changes which have persisted because of their

adaptational advantages? From what we know of the origin of inheritable variations in other animals, it would seem more reasonable to assume that such structures have arisen as mutations rather than through any Lamarckian influences. Such a conclusion would be in harmony with the suggestions made by such recent writers on the subject of evolution as Metcalf (1928), Kofoid (1930), Davenport (1930), Morgan (1932), Haldane (1932), Goldschmidt (1933) and Conklin (1934).

It has frequently been pointed out in this paper that the same species of parasite or very nearly related species of parasite may live in a number of different kinds of hosts, sometimes in hosts which are taxonomically far apart. Also that the same species of host may harbor a number of species of the same genus of parasite. These facts suggest that the origin of species is not primarily due to changes of an adaptational character, induced by the host environment, in a Lamarckian sense, but that morphological and physiological mutations take place from time to time and thus provide the material upon which natural selection would work. In the case of any of these mutations, it may be assumed that they may appear either "spontaneously," that is without known causes, or may be stimulated by some definite environmental agency, and that natural selection would determine their survival value.

V. Summary

1. The protozoa, as the oldest phylum of animals, have had a longer time than any other phylum in which to undergo evolution within the group and to invade all possible environments.

2. The wide-spread distribution of the protozoa has provided extensive opportunities for them to attach themselves to and to be taken into the bodies of other animals. Those with appropriate characteristics could become ectozoic or endozoic associates.

3. The parasitic habit has been successfully assumed by

many different kinds of protozoa. Nearly every order contains some parasitic members and some entire genera, families, orders and even entire classes (Sporozoa and Opalinata) are now parasitic.

4. Among the associated protozoa we find every gradation from early stages of facultative invasion of hosts to highly modified forms with rigid host specificity. At one extreme we have free-living forms capable of living endozoically for a time when opportunity affords (*Menoidium* sp. and *Euglena gracilis* in the milliped). Next in order are species that have become definitely endozoic but are only slightly different from their nearest free-living relatives (*Euglena leucops, Euglenamorpha hegneri;* species of *Metopus,* etc., in sea urchins; species of *Hexamita*). At the other extreme are the highly evolved gregarines and astomatous ciliates with especially adapted structures for attachment to the host and a high degree of host specificity. Between these extremes can be found practically every possible degree of host-parasite relation.

5. There are many interesting contrasts, even among closely related groups. The gregarines are limited to the invertebrates and lower chordates while the nearly related Coccidia are found in all classes of vertebrates and in many of the invertebrate phyla. Within the Coccidia the genus *Wenyonella* is thus far represented by a single species in one reptilian host while the genus *Eimeria* has had 220 species assigned to it from all classes of vertebrates and from some invertebrates. Members of the genus *Giardia* are limited to vertebrates and show a high degree of host specificity, while the species of the nearly related genus, *Hexamita,* are found in nearly all possible environments, including both fresh and salt water, and located upon or within animals belonging to many different phyla and they show much less host specificity.

6. Evolution of species has been extensive in some groups and slight in others. Extensive evolution of species has taken place in the ciliate Family Ophryoscolecidæ in the ruminants and in the Cycloposthiidæ in the Equidæ; the polymastigote and hypermastigote flagellates have undergone extensive

evolution of genera and species in the termites and wood roaches; the Trypanosomatidæ have not only evolved a great many species but they have spread to a large number of different kinds of hosts. By contrast, apparently little change has taken place since the endozoic habit was established in such groups as the endozoic euglenoids and certain of the ciliates found in sea urchins.

7. In many groups of parasitic protozoa there is little parallelism between the evolution of species of parasite and evolution of species of host. as for example, among the endozoic amœbæ, the trypanosomes and the trichomonad flagellates.

8. In some groups of protozoa there seems to be a great deal of host specificity without corresponding recognizable morphological differences. In such cases the idea of physiological varieties or species may be justifiable.

9. The evidence presented indicates (1) that in many cases the same or nearly related species have invaded many hosts belonging to widely different taxonomic groups; (2) that a number of species of the same genus may be found in the same species of host and (3) that one species of host may harbor many species of parasites belonging to widely different groups. Such evidence does not suggest that the host, as a specific type of environment, has had a directive influence upon the evolution of species of parasite in a Lamarckian sense. Rather, the evidence points to a mutational origin of new characters, both the physiological (without visible morphological accompaniments) and the visibly morphological. Mutations may result from definite environmental stimuli and natural selection would determine their survival value.

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VI. LIST OF REFERENCES

ALEXEIEFF, A. 1914. Notes protistologiques. Zool. Anz. 44: 193–213.
ALEXEIEFF, A. AND GWÉLÉSSIANY. 1929. Sur le mechanism de la specificité parasitaire chez les *Trichomonas*. C. R. Soc. Biol. 100: 314–316.

ANDREWS, J. 1927. Host-parasite specificity in the coccidia of mammals. Jour. Parasitol. 13: 183–194.

———. 1932. Cysts of the dysentery-producing *Endamœba histolytica* in Baltimore dogs. The Am. Jour. Trop. Med. 12: 401–404.

BECKER, E. R. 1923. Transmission experiments on the specificity of *Herpetomonas musca-domesticæ* in muscoid flies. Jour. Parasitol. 10: 25–34.

———. 1933a. Cross-infection experiments with Coccidia of rodents and domestic animals. Jour. Parasitol. 19: 230–234.

———. 1933b. Host-specificity and specificity of animal parasites. Am. Jour. Trop. Med. 13: 505–523.

———. 1934. Coccidia and coccidiosis of domesticated, game and laboratory animals and of man. Collegiate Press, Inc., Ames, Iowa.

BECKER, E. R. AND TALBOT, M. 1927. The protozoan fauna of the rumen and reticulum of American cattle. Iowa State Coll. Jour. Sci. 1: 345–373.

BHATIA, B. L. AND GULATI, A. N. 1927. On some parasitic ciliates from Indian frogs, toads, earthworms and cockroaches. Arch. f. Protistenk. 57: 85–120.

BIGGAR, R. B. 1932. Studies on ciliates from Bermuda sea urchins. Jour. Parasitol. 18: 252–257.

BRUG, S. L. 1919. De entamœben van de rat. Geneesk. Tijd. Nederl. Indië. 59: 1–15.

BRUMPT, E. ET LAVIER, G. 1924. Un nouvel Euglénien polyflagellé parasite du têtard de *Leptodactylus ocellatus* au Brásil. Ann. Parasitol. Hum. et Comp. 2: 248–252.

BUISSON, J. 1923. Les Infusoires ciliés du tube digestif de l'homme et des mammifères. Travail du Lab. de Parasitol. de la Faculté de Médicine de Paris. Amedee Legrand, Ed.

CALKINS, G. N. 1933. Biology of the protozoa. Lea and Febiger, Philadelphia.

CARINI, A. 1933. Sobre uma nova *Zelleriella* (*Z. jægeri*, n.sp.) do intestino de uma cobra. Arch. Biol. 16: 59.

CÉPÈDE, C. 1910. Recherches sur les infusoires astomes. Anatomie, biologie, ethologie parasitaire, systematique. Arch. de Zool. exp. et gen. 53: 341–609.

CHIANG, S. F. 1925. The rat as a possible carrier of dysentery amœba. Proc. Nat. Acad. Sci. 11: 239–246.

CLEVELAND, L. R., HALL, S. R., SANDERS, E. AND COLLIER, J. 1934. The wood-feeding roach, *Cryptocercus*, its protozoa, and the symbiosis between protozoa and roach. Mem. Amer. Acad. Arts and Sci. 17: 185–342.

CONKLIN, E. G. 1934. A generation's progress in the study of evolution. Science, 80: 147–156.

CRAWLEY, H. 1923. Evolution in the ciliate family Ophryoscolecidæ. Proc. Acad. Nat. Sci., Philadelphia, 75: 393–412.

CUNHA, A. DA AND MUNIZ, J. 1927. Trois nouvelle espèces du genre Cycloposthium. C. R. Soc. Biol. 96: 494–496.

DAVENPORT, C. B. 1930. The mechanism of organic evolution. Jour. Wash. Acad. Sci. 20: 317–331.

DOBELL, C. 1932. Antony van Leeuwenhoek and his " Little Animals." Harcourt, Brace and Co., New York.

———. 1933. Researches on the intestinal protozoa of monkeys and man. V. The *Endolimax* of macaques. Parasitol. 25: 436–467.

DOGIEL, V. A. 1927. Monographie der Familie Ophryoscolecidæ. Arch. f. Protistenk. 59: 1–288.

FANTHAM, H. B. 1932. Some parasitic protozoa found in South Africa. XV. S. Afric. Jour Sci. 29: 627–640.

FANTHAM, H. B. AND PORTER, A. 1914. Some minute animal parasites. Methuen and Co., Ltd., London.

GOLDSCHMIDT, R. 1933. Some aspects of evolution. Science, 78: 539–547.

GOODRICH, H. P. AND MOSELEY, M. 1916. On certain parasites of the mouth in cases of pyorrhea. Jour. R. Mic. Soc. (1916): 513–527.

GOWAN, J. W. 1933. On the genetic structure of inherited constitution for disease resistence. Quart. Rev. Biol. 8: 338–347.

HALDANE, J. B. S. 1932. The causes of evolution. Harper and Bros., New York.

HALL, S. R. 1931. Observations on *Euglena leucops*, sp. nov., a parasite of *Stenostomum*, with special reference to nuclear division. Biol. Bull. 60: 327–344.

HEGNER, R. 1923. Observations and experiments on Euglenoidina in the digestive tract of frog and toad tadpoles. Biol. Bull. 45: 162–180.

——. 1927. Excystation and infection in the rat with *Giardia lamblia* from man. Amer. Jour. Hyg. 7: 433–447.

——. 1928. The evolutionary significance of the protozoan parasites of monkeys and man. Quart. Rev. Biol. 3: 225–244.

——. 1929. Transmission of intestinal protozoa from man and other animals to parasite-free fowls. Am. Jour. Hyg. 9: 529–543.

——. 1930. Host-parasite specificity in the genus *Giardia*. In: Hegner and Andrews. Problems and methods of research in protozoölogy, Chap. XV. The Macmillan Co., New York.

——. 1934a. Specificity in the genus *Balantidium* based upon size and shape of body and macronucleus, with descriptions of six new species. Am. Jour. Hyg. 19: 38–67.

——. 1934b. Intestinal protozoa of chimpanzees. Am. Jour. Hyg. 19: 450–501.

HEGNER, R. AND CHU, H. J. 1930. A comparative study of the intestinal protozoa of wild monkeys and man. Amer. Jour. Hyg. 12: 62–108.

HOARE, C. A. 1933. Studies on some new ophidian and avian coccidia from Uganda, with a revision of the classification of the Eimeriïdæ. Parasitol. 25: 359–388.

HOLMES, F. O. 1930. Protozoa of latex plants. In: Hegner and Andrews. Problems and methods of research in protozoölogy, Chap. XXIX. The Macmillan Co., New York.

HSIUNG, T. S. 1930. A monograph on the protozoa of the large intestine of the horse. Iowa State Coll. Jour. Sci. 4: 359–423.

——. 1931. The protozoan fauna of the rumen of the Chinese sheep. Bull. Fan Mem. Inst. Biol. 2: 29–43.

——. 1932. A general survey of the protozoan fauna of the rumen of the Chinese cattle. Bull. Fan Mem. Inst. Biol. 3: 87–107.

JOHNSON, P. D. 1933. A case of infection by *Trypanosoma lewisi* in a child. Trans. Roy. Soc. Trop. Med. and Hyg. 26: 467–468.

KAHL, A. 1932. Die Tierwelt Deutschlands, usw. 25 Teil. Urtiere oder Protozoa. I. Wimpertiere oder Ciliata (Infusoria). 3. Spirotricha. Pp. 399–650.

KAMM, M. W. 1922. Studies on gregarines. II. Synopsis of the polycystid gregarines of the world, excluding those from the Myriopoda, Orthoptera and Coleoptera. Ill. Biol. Monog. 7: 1–104.

KESSEL, J. F. 1923. Experimental infection of rats and mice with the common intestinal amœbæ of man. Univ. Calif. Pub. Zoöl. 20: 409–430.

——. 1928a. Host-parasite relationships of certain intestinal protozoa important in medical zoölogy. Jour. Am. Med. Assoc. 90: 1089–1092.

——. 1928b. Amœbiasis in kittens infected with amœbæ from acute and " carrier " human cases and with the tetranucleate amœba of the monkey and of the pig. Am. Jour. Hyg. 8: 311–355.

KIRBY, H., JR. 1930. The protozoa of termites. In: Hegner and Andrews. Problems and methods of research in protozoölogy, Chap. V. The Macmillan Co., New York.

KOFOID, C. A. 1930. Factors in the evolution of the pelagic ciliata, the Tintinnoinea. Contrib. to Mar. Biol., pp. 1–39. Stanford Univ. Press.

KOFOID, C. A. AND MacLENNAN, R. F. 1933. On the ciliate fauna of the Indian humped ox, *Bos indicus* Linn. III. *Epidinium* Crawley, *Epiplastron*, Gen. Nov. and *Ophryoscolex* Stein. Univ. of Calif. Pub. Zool. 39: 1–34.

KUDO, R. 1919. Studies on Myxosporidia. A synopsis of genera and species of Myxosporidia. Ill. Biol. Monog. 5(3/4): 1–265.

——. 1924. A biologic and taxonomic study of the Microsporidia. Ill. Biol. Monog. 9(2/3): 1–268.

——. 1933. A taxonomic consideration of Myxosporidia. Trans. Am. Mic. Soc. 52: 195–216.

LAVIER, G. 1927. *Protoopalina nyanza*, n. sp., opaline parasite d'un reptile. C. R. Soc. Biol. Paris, 97: 1709–1710.

LEVINE, N. D. AND BECKER, E. R. 1933. A catalogue and host index of the species of the coccidian genus *Eimeria*. Iowa State Coll. Jour. Sci. 8: 83–106.

LUCAS, M. S. 1934. Ciliates from Bermuda sea urchins. I. Metopus. Jour. Roy. Mic. Soc. 54: 79–93.

LYNCH, J. E. 1930. Studies on the ciliates from the intestine of *Strongylocentrotus*. II. *Lechriopyla mystax*, gen. nov., sp. nov. Univ. Calif. Pub. Zool. 33: 307–350.

LYNCH, K. M. 1915. The rat a carrier of a dysenteric amœba. Jour. Am. Med. Assoc. 65: 2232–2234.

METCALF, M. M. 1909. *Opalina*. Its anatomy and reproduction with a description of infection experiments and a chronological review of the literature. Arch. f. Protistenk. 13: 195–375.

——. 1923. The opalinid ciliate infusorians. Smiths. Inst. U. S. Nat. Mus. Bull. 120: 1–484.

——. 1928. Trends in evolution: a discussion of data bearing upon orthogenesis. Jour. Morph. and Physiol. 45: 1–45.

MORGAN, T. H. 1932. The scientific basis of evolution. W. W. Norton and Co., Inc., New York.

NIESCHULZ, O. 1924. Amoben aus den Zahnbelag von Pferden. Arch. Tierheilk. 51: 41.

NÖLLER, W. 1931. Die nächsten Verwandten der Blutflagellaten und ihre Beziehungen zu den blutbewohnden Formen. In Prowazek's Handbuch der Pathogenen Protozoen, 3: 1069–2143.

OGUMA, K. 1931. On a species of *Trichomonas* parasitic on pigeon squabs. Jour. Fac. Sci. Hokkaido Imp. Univ. Ser. VI. 1: 117–131.

POTTER, L. A. 1927. Two species of *Giardia* from the rat. Amer. Jour. Hyg. 8: 77–84.

POWERS, P. B. A. 1933. Studies on the ciliates from sea urchins. II. *Entodiscus borealis* (Hentschel) (Protozoa, Ciliata). Behavior and morphology. Biol. Bull. 65: 122–136.

RATCLIFFE, H. L. AND GEIMAN, Q. M. 1934. Amœbiasis in reptiles. Science, 79: 324–325.

REGENDANZ, P. 1929. Ueber die Uebertragung der *Entamœba histolytica*, *Entamœba coli* und *Dientamœba fragilis* auf Ratten. Centralbl. Bakt. I. Abt. Orig. 111: 412–419.

REYNOLDS, B. D. 1930. Ectoparasitic protozoa. In: Hegner and Andrews. Problems and methods of research in protozoology. Chap. III. The Macmillan Co., New York.

SCHUMAKER, E. 1930. *Balantidium coli*: host specificity and relation to the diet of an experimental host. Amer. Jour. Hyg. 12: 341–365.

SIMIĆ, T. 1933. Le *Trichomonas parva* Alex. du rat est il le meme que le *Trichomonas intestinalis* Leuck. de l'homme? Ann. Parasitol. hum. et comp. 11: 7–16.

SMITH, S. C. 1928. Host-parasite relations between *Iodamœba williamsi* and certain mammalian hosts. Amer. Jour. Hyg. 8: 1–15.

SMITH, T. 1934. Parasitism and disease. Princeton Univ. Press, Princeton.

TALIAFERRO, W. H. 1929. The immunology of parasitic infections. The Century Co., New York.

TYZZER, E. E. 1929. Coccidiosis in gallinaceous birds. Am. Jour. Hyg. 10: 269–383.

UYEMURA, M. 1934. Ueber einige neue Ciliaten aus dem Darmkanal von Japanischen Echinoideen. Sci. Rep. Tokyo Bun. Daig. Sect. B. No. 17, pp. 181–191.

WATSON, M. E. 1916. Studies on gregarines, including descriptions of 21 new species and a synopsis of eugregarine records from the Myriopoda, Coleoptera and Orthoptera of the world. Ill. Biol. Monog. 2(3): 1–258.

WENRICH, D. H. 1924a. Studies on *Euglenamorpha hegneri*, n. gen., n. sp., a euglenoid flagellate found in tadpoles. Biol. Bull. 47: 149–174.

——. 1924b. A new protozoan, *Amphileptus branchiarum*, n. sp., on the gills of tadpoles. Trans. Am. Mic. Soc. 43: 191–199.

——. 1924c. Protozoa on the skin and gills of tadpoles. Trans. Am. Mic. Soc. 43: 200–202.

——. 1931. Morphological studies on the trichomonad flagellates of man. Archiv. de la Soc. Biol. Montevideo. Suppl. Actas Congreso intern. Biol. de Montevideo. Fasc. 5: 1185–1199.

WENRICH, D. H. AND YANOFF, J. 1927. Results of feeding active trichomonad flagellates to rats. Am. Jour. Hyg. 7: 119–124.

WENYON, C. M. 1926. Protozoölogy. Wm. Wood and Co., New York.

VII. EXPLANATION OF FIGURES

Unless otherwise stated drawings have been made by the writer from his own collection of prepared slides. Magnifications are indicated for each drawing or plate, based upon one-half reduction from the original drawings.

PLATE I

FIG. 1. *Leptotheca ohlmacheri*, a disporic myxosporidian from the kidney of the frog, *Rana pipiens* ($\times$ 1500).

FIG. 2. *Nosema apis*, a microsporidian, from the honey bee. *a.* Part of cross section of bee's stomach; stippled areas showing spores ($\times$ 30). *b.* A single spore ($\times$ 2000).

FIG. 3. *Actinocephalus dujardini*, cephaline gregarine from intestine of centipede, *Lithobius* sp. ($\times$ 500).

FIG. 4. *Eimeria stiedæ*, various stages in epithelial layer in the liver of a rabbit ($\times$ 500).

FIG. 5. *Zelleriella* sp. from tree frog, *Hyla cinerea* ($\times$ 500). An apparently identical species was found in a Cuban tree boa, *Tropidophis melanurus*.

FIG. 6. *Hoplitophrya lumbrici* (?), astomatous ciliate from intestine of an earthworm ($\times$ 500).

FIG. 7. *Amphileptus branchiarum*, ciliate on gills of frog tadpoles. Note partially ingested mass of gill cells ($\times$ 500). (After Wenrich, 1924b, Fig. 11.)

FIG. 8. *Nyctotherus velox*, from intestine of the milliped, *Spirobolus marginatus* ($\times$ 500).

FIG. 9. *Balantidium sp.* from a chimpanzee newly arrived from Africa ($\times$ 500).

FIG. 10. *Diplodinium dentatum*, from stomach of domestic ox ($\times$ 500).

FIG. 11. *Cycloposthium compressum*, from cæcum of rodent, *Hydrochærus capybara* ($\times$ 500). (From material collected in Panama by Dr. R. M. Stabler.)

PLATE II

(All figures $\times$ 1500)

FIG. 12. *Endolimax nana*, trophozoite, from man.

FIG. 13. *Endolimax caviæ*, trophozoite, from guinea pig.

FIG. 14. *Endolimax ranarum*, trophozoite, from frog, *Rana pipiens*.

FIG. 15. *Endolimax blattarum*, trophozoite, from cockroach, *Periplaneta americana*.

FIG. 16. *Endolimax* sp., trophozoite, from milliped, *Spirobolus marginatus*.

FIG. 17. *Endolimax* sp., trophozoite, from crane-fly larva. (From slide prepared by Dr. Q. M. Geiman.)

FIG. 18. *Endolimax* sp., trophozoite, from Japanese beetle larva.

FIG. 19. *Dientamœba fragilis*, trophozoite, from man.

FIG. 20. *Dientamœba fragilis*, trophozoite, from monkey. (After Hegner and Chu, 1930, Fig. 10.)

FIGS. 21 and 22. *Iodamœba butschlii*, trophozoite and cyst, from man.

FIG. 23. *Iodamœba butschlii*, trophozoite, from chimpanzee.

FIG. 24. *Iodamœba butschlii*, cyst, from monkey, *Macacus irus*.

FIGS. 25 and 26. *Endamœba histolytica*, trophozoite and cyst, from man.

FIGS. 27 and 28. *Endamœba histolytica* (?), trophozoite and cyst, from Norway rat.

FIGS. 29 and 30. *Endamœba ranarum*, trophozoite and cyst from frog, *Rana clamitans*.

FIGS. 31 and 32. *Endamœba* sp., trophozoite and cyst, from young diamondback turtle.

FIGS. 33 and 34. *Endamœba thomsoni*, trophozoite and cyst, from cockroach, *Periplaneta americana.*

FIG. 35. *Endamœba minchini*, trophozoite, from crane-fly larva. (From slide prepared by Dr. Q. M. Geiman.)

Fig. 36. *Endamœba* sp., trophozoite, from Japanese beetle larva.

FIGS. 37 and 38. *Endamœba coli*, trophozoite and cyst from man.

FIGS. 39 and 40. *Endamœba muris*, trophozoite and cyst, from Norway rat.

PLATE III

(All figures × 2000)

FIG. 41. *Euglenamorpha hegneri*, from intestine of frog tadpole.

FIG. 42. *Euglenamorpha hegneri*, with some of the characters of *E. pellucida.*

FIG. 43. *Euglenamorpha pellucida*, colorless species with six flagella. (Figures 41, 42, and 43 from same slide.)

FIG. 44. *Trypanosoma* sp., from blood of frog, *Rana aurora draytoni.*

FIG. 45. *Trypanosoma gambiense*, cause of African sleeping sickness in man.

FIG. 46. *Herpetomonas (Phytomonas) bancrofti*, from latex of fig, *Ficus scabra.* (From slide by Dr. F. O. Holmes.)

FIG. 47. *Herpetomonas muscarum*, from intestine of house fly.

FIG. 48. *Leishmania donovani*, cause of kala azar in man, flagellate stage from culture. (Commercial slide.)

FIG. 49. *Leishmania donovani*, aflagellate stages in endothelial cell of human spleen.

FIG. 50. *Giardia muris*, from small intestine of Norway rat.

FIG. 51. *Trichomonas termitidis* from termite. (From slide prepared by Dr. Misao Tanabe.)

FIG. 52. *Holomastigotes* sp., hypermastigote flagellate from *Reticulitermes flavipes.* (From slide prepared by Dr. R. M. Stabler.)

PLATE IV

(All figures × 2000)

FIG. 53. *Trichomonas elongata*, from human mouth.

FIG. 54. *Trichomonas vaginalis*, from human vagina.

FIG. 55. *Trichomonas columbæ*, from crop of pigeon. (After Oguma, 1931, Fig. 4.)

FIG. 56. *Trichomonas hominis*, from intestine of man.

FIG. 57. *Trichomonas hominis* (?), from cæcum of Norway rat.

FIG. 58. *Trichomonas hominis* (?), from intestine of rhesus monkey.

FIG. 59. *Trichomonas fecalis*, from intestine of man.

FIG. 60. *Trichomonas batrachorum*, from intestine of frog.

FIG. 61. *Trichomonas* sp., from cæcum of Norway rat.

FIG. 62. *Trichomonas muris*, from cæcum of Norway rat.

FIG. 63. *Trichomonas* sp., from intestine of rhesus monkey.

FIG. 64. *Trichomonas fœtus*, from vagina of domestic cow.

FIG. 65. *Trichomonas caviæ*, from cæcum of guinea pig.

FIG. 66. *Trichomonas augusta*, from intestine of frog, *Rana pipiens.*

PLATE V

(All figures × 2000)

FIG. 67. *Hexamita intestinalis* (?), from intestine of frog, *Rana pipiens*.

FIG. 68. *Hexamita intestinalis* (?), from intestine of frog. *R. pipiens*.

FIG. 69. *Hexamita* sp., from intestine of marine fish, *Box boops*. (From slide made in Naples by Mr. P. B. A. Powers.)

FIG. 70. *Hexamita* sp., from intestine of cricket frog, *Acris gryllus*.

FIG. 71. *Hexamita* sp., from intestine of salamander, *Desmognathus* sp.

FIG. 72. *Hexamita* sp. (*Urophagus* type). from intestine of frog, *Rana pipiens*.

FIG. 73. *Hexamita* sp., from skin of marine fish, *Fundulus heteroclitus*.

FIG. 74. *Hexamita* sp., from intestine of milliped, *Spirobolus marginatus*.

FIG. 75. *Hexamita lateralis*, from intestine of crane-fly larva.   (From slide prepared by Dr. Q. M. Geiman.)

FIG. 76. *Hexamita periplanetæ*, from intestine of cockroach, *Periplaneta americana*.

FIG. 77. *Hexamita batrachorum* (*Octomastix b.*) from intestine of frog, *Rana pipiens*.

FIG. 78. *Hexamita parva* (*Octomastix p.*), from intestine of young *diamond-back* turtle.

FIG. 79. *Hexamita pitheci* (?), from intestine of rhesus monkey.

FIG. 80. *Hexamita* sp. (*Octomitus* type), from intestine of frog, *Rana pipiens*.

FIG. 81. *Hexamita* sp. (*Octomitus* type), from intestine of salamander, *Desmognathus* sp.

FIG. 82. *Hexamita pulcher*, from cæcum of house mouse.

FIG. 83. *Hexamita muris*, from small intestine of house mouse.

FIG. 84. *Hexamita* sp., from foul ditch water.

FIG. 85. *Hexamita* sp., from outside of dead freshwater snail.

FIG. 86. *Hexamita rostrata* (?), from outside of dead freshwater snail.

PLATE I

PLATE II

t

PLATE III

41   42   43   46   47   48   49   44   45   50   51   52

PLATE IV

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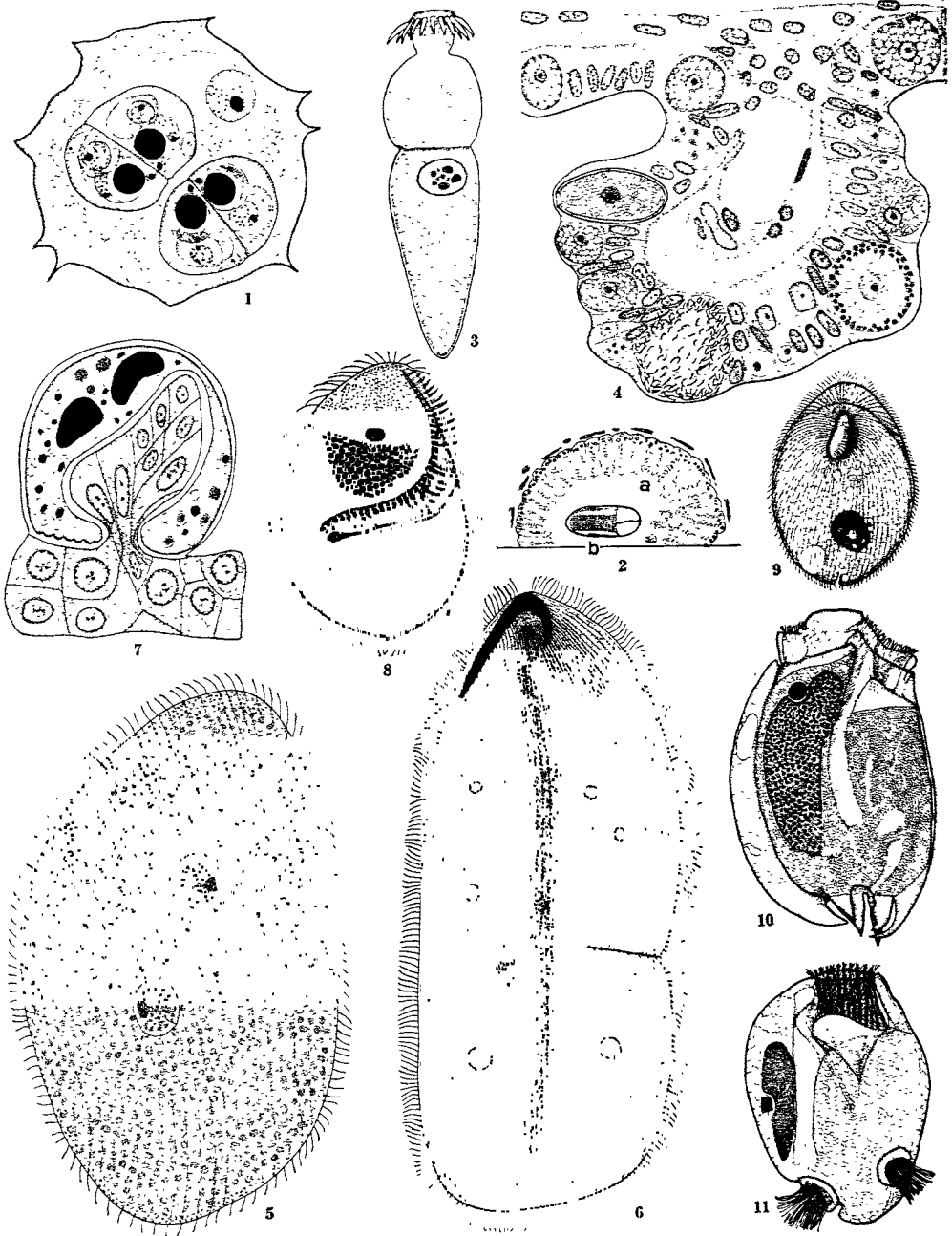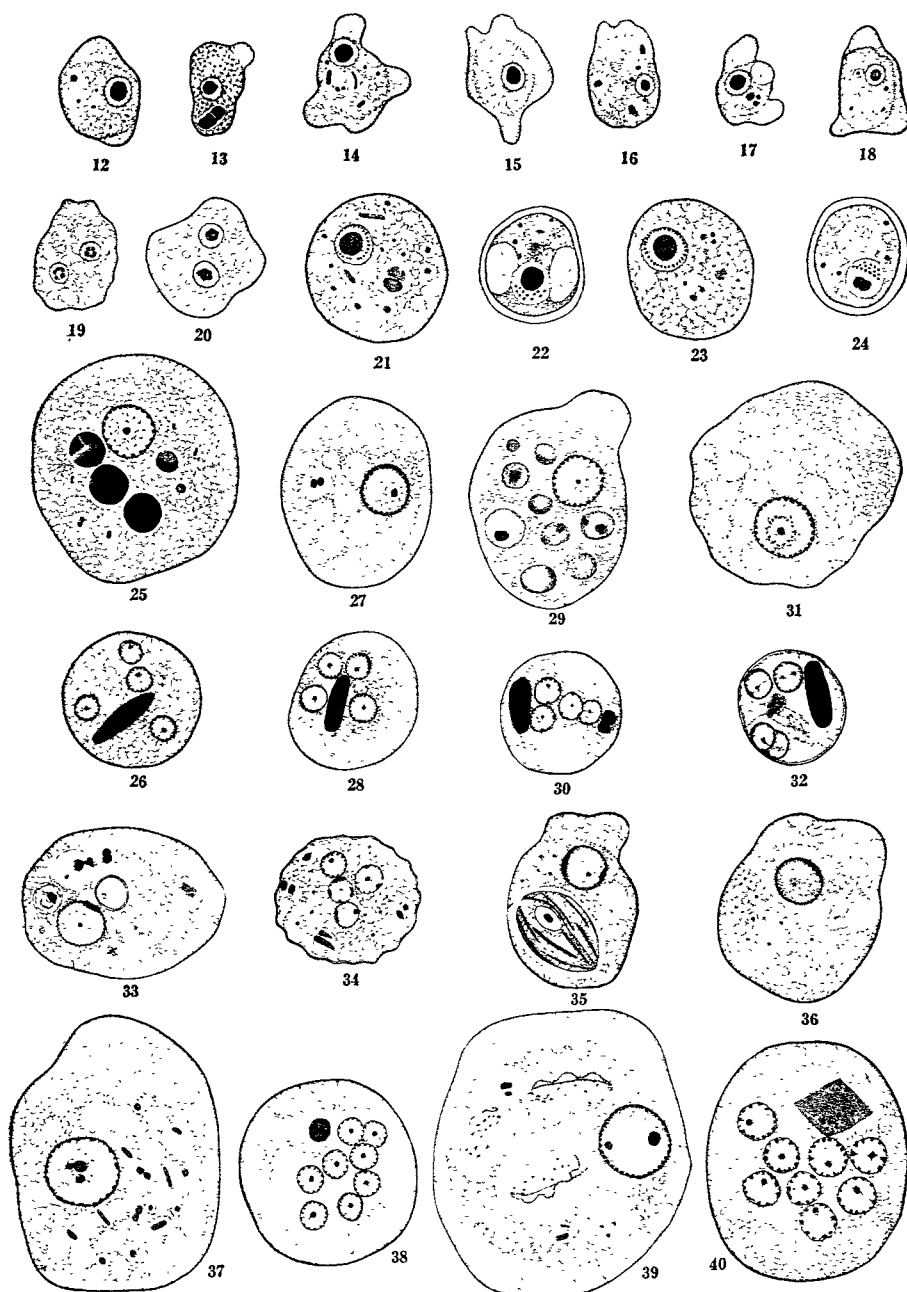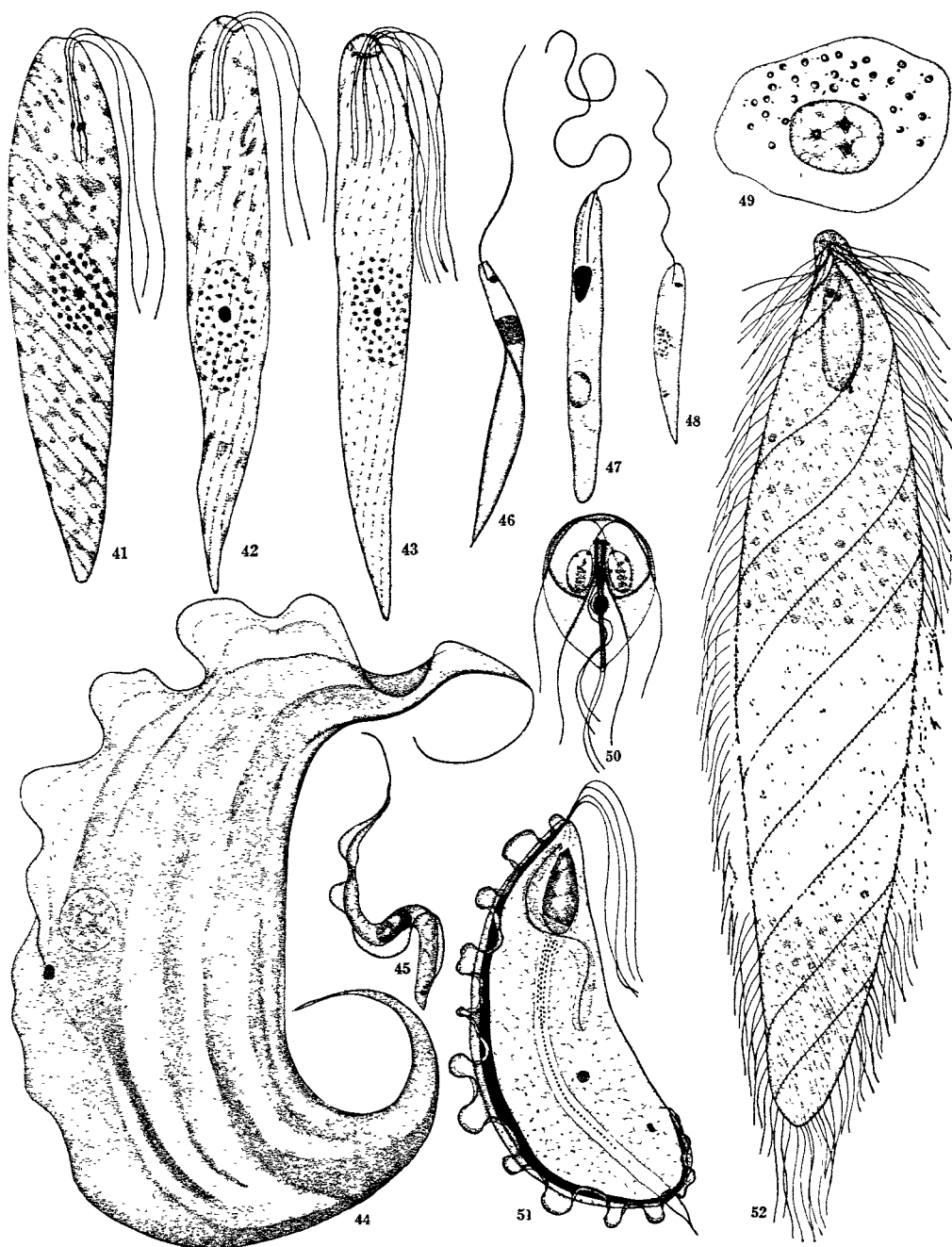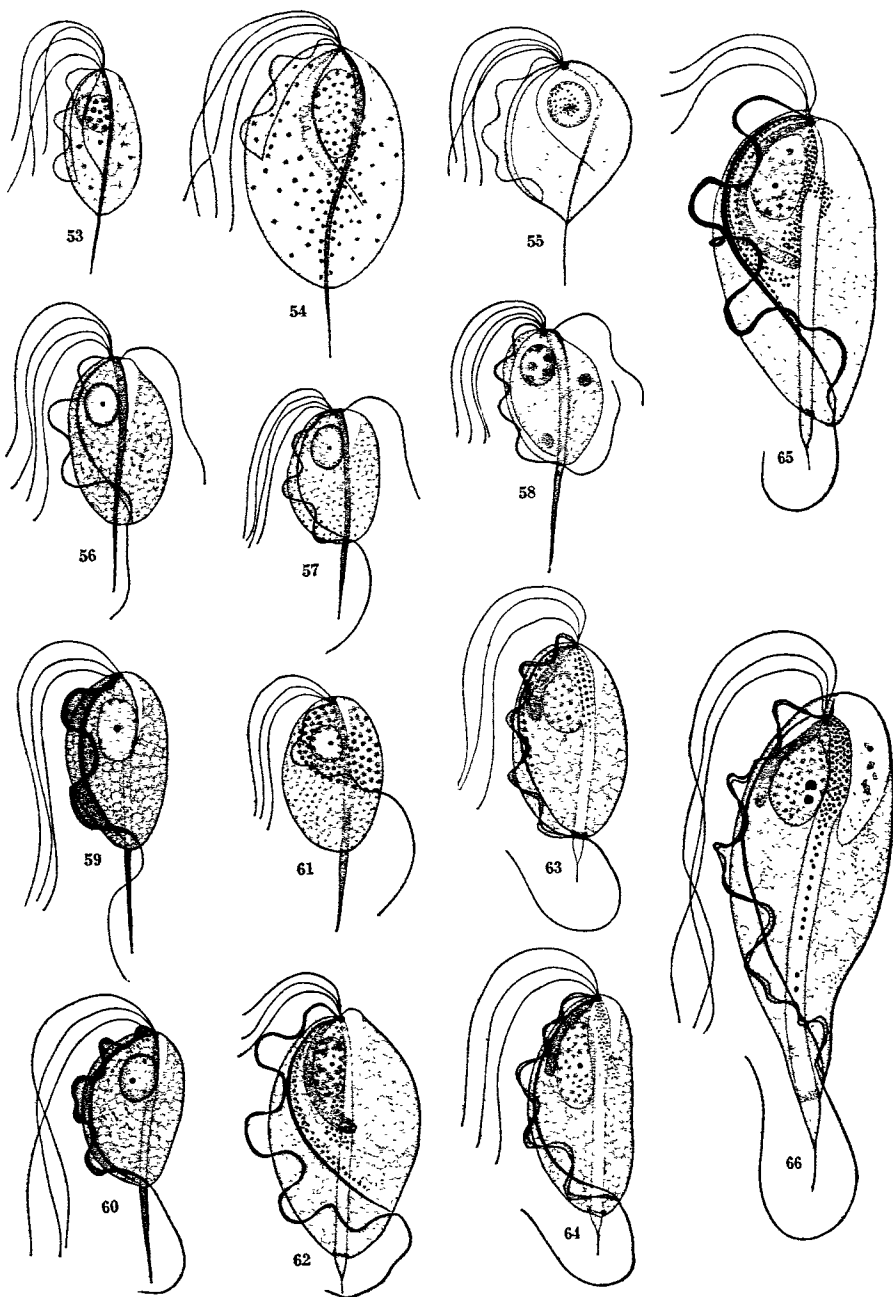
PLATE V
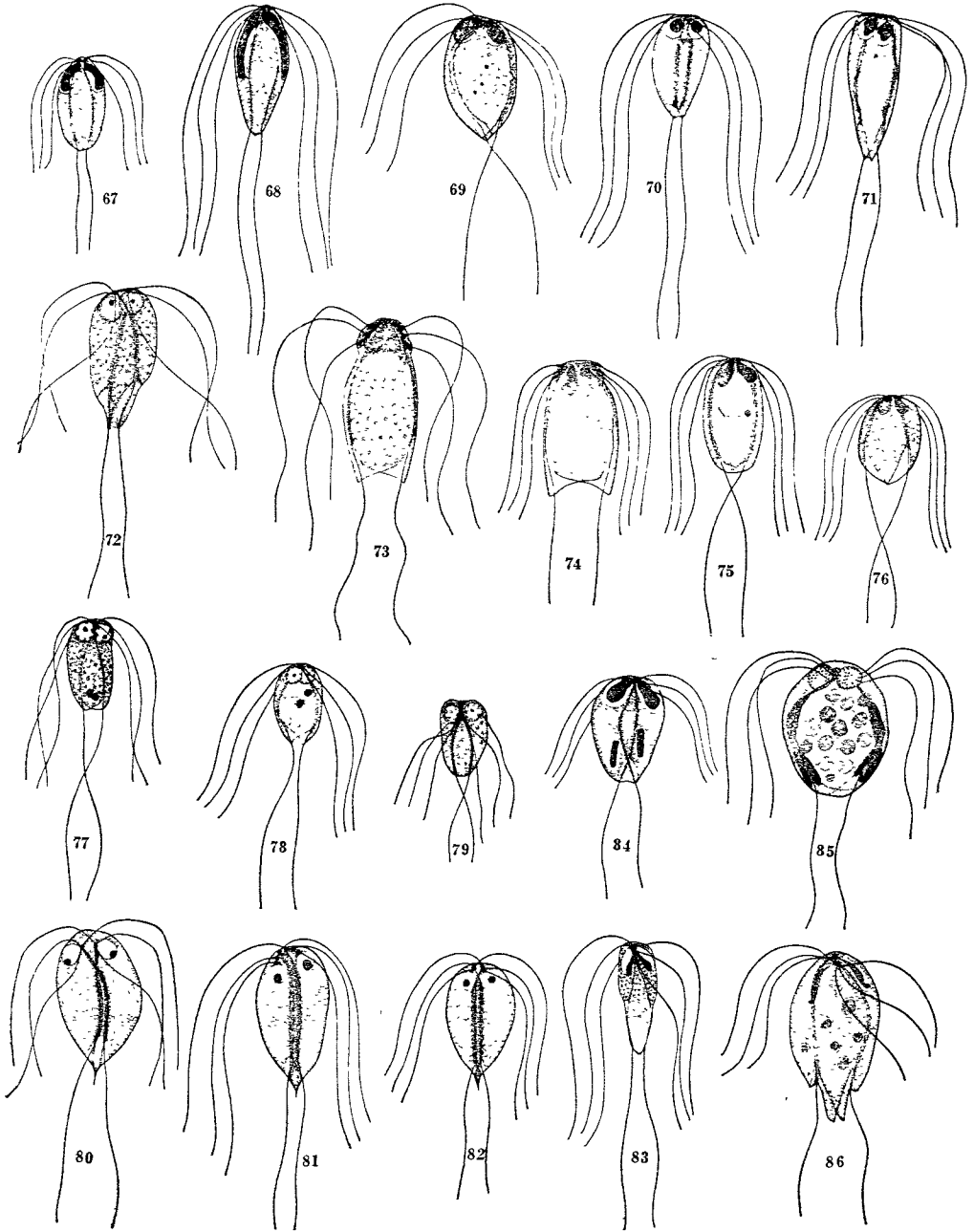
ON THE INTERPRETATION AND DATING OF THE SITE OF "BELO BRDO" AT VINČA IN YUGOSLAVIA

VLADIMIR J. FEWKES

In his recent publication, Professor M. M. Vasić, the excavator of the famous site of "Belo Brdo" at Vinča, near Belgrade, Yugoslavia, declares: ". . . Vinča a été fondée comme une colonie ionienne . . . a existé, sans interruptions, jusqu'à l'arrivée des Romains dans cette region, en l'année 6 après J. Chr. Il faut supposer que la fondation de Vinča eut lieu aux environs de l'année 600 av. J. Chr."[1] This view represents the most radical departure from the course previously followed by the distinguished author. It should mark the *terminus post quem*, as it were, in his long and varied record of dating and interpreting Vinča, for, as he maintains, there are no Roman remains at the site.[2] For practically thirty years, and especially so during the last decade, Vinča has been the chief concern of Professor Vasić's labors. There have been many interruptions in his active field work, all totally out of his control, and the excavations are not yet finished. However the record of his datings and general interpretations of the site present a unique phenomenon. Considered in the chronological order of their appearance, the major features may be tabulated as follows:

1905: "The larger portion of the culture deposits (*i.e.* in vertical distribution) of Vinča belongs to the metal epochs,"[3] the site is "younger than *Čaršija*,"[4] and may, on the whole, be dated "from the end of the Neolithic to the so-called Hallstatt period."[5]

[1] " Colons grecs a Vinča," *Revue International des Etudes Balkaniques*, I (1934), pp. 70 and 71. (Hereafter cited as *R. I. E. B.*)
[2] *Preistorijska Vinča I*, etc. (Beograd, 1932), p. 97. (Hereafter *P.V.I.*)
[3] *Godišnjak Srpske Kraljevske Akademije*, XIX (1905), p. 259. (Hereafter *Godiš.*)
[4] *Ibid.*, p. 262.
[5] *Ibid.*, pp. 262-3.

1906: "Vinča belongs to the Neolithic Age . . . and is younger than *Čaršija* and *Mali Drum*."[6]   (This is the only instance of so early a dating.)

1906: ". . . sites of the Bronze Age, such as Vinča . . .,"[7] and further ". . . in the main Vinča must be dated as of the Metal Age."[8]

1907: Vinča corresponds to oldest Troy and is to be dated "vom Ende der Steinzeit bis zum Anfang der Eisenzeit, wen nicht noch viel weiter herunter."[9]

1908: "The date of Vinča falls between the beginning of Troy II and the end of Troy VII."[10]

1911: As "metallzeitlich[11] . . . ist . . . Vinča nach dem Anfang von Troja II bis vielleicht zum Ende der La-Tènezeit zu datieren."[12]

1930: ". . . exclusively economic and commercial connections with the Southeast, and not colonization, help us to explain the dating of the beginning of Vinča after the commencement of Troy II."[13]

1932: "The culture deposit at Vinča, 10.5 m. thick, is divisible, on the basis of characteristic differences, into thinner levels corresponding to shorter periods of time within the interval of from about 1600 B.C. to about 6 A.D.[14] . . . The colonists who founded Vinča came from the Cyclades[15] . . . at the beginning of the Late Cycladic (L. C.) or Late Minoan (L. M.) period[16] . . . Geographic and other factors (*i.e.* ores) strongly suggest that Vinča controlled the shipping and commerce of the Middle Danube, and so the trade directed towards the Ægean.[17] . . . The hyperboreal myth is not as

[6] *Glas Srpske Kraljevske Akademije*, LXX (1906), pp. 165–6.   (Hereafter *Glas.*)
[7] *Starinar*, n.r.g. I, 1(1906), p. 34.   (Hereafter *Star.*)
[8] *Ibid.*, I, 2 (1906), p. 126.
[9] *Memnon*, I, 2 (1907), p. 187.
[10] *Godiš.*, XXII (1908), p. 160.
[11] *Prähistorische Zeitschrift*, III, 1/2 (1911), p. 127.   (Hereafter *P. Z.*)
[12] *Ibid.*, p. 131.
[13] *Man*, XXX (1930), p. 200.
[14] *P. V. I*, p. 97.
[15] *Ibid.*, p. 149.
[16] *Ibid.*, p. 150.
[17] *Ibid.*, p. 151.

legendary as is thought.[18] . . . Starting from the Ægean and the Cyclades, the Ægean culture ended its missionary role in the Danube Valley in the Late Minoan time (L. M.)." [19]

1932: Vinča is reiterated as a Cycladic colony, which was founded in the M. M. II–III time.[20]

1934: As cited at the outset of this paper, Vinča is held to be an Ionian colony.[21]

Barring the single instance of Neolithic dating, Vasić's interpretations fall within three periods. In the first, Vinča represents a heritage of Troy II which is not to be explained by colonization. This view prevails in Vasić's writing up to and inclusive of 1930. It must be pointed out, however, that the last article of this period was written before the field campaign of 1930 was closed.[22] There were no excavations at Vinča during the season of 1932. The second period, in which Vinča is an Ægean, or more specifically a Cycladic, colony is one of a brief duration. The book expounding this thesis [23] is a learned discourse in which the author treats of many and varied aspects involving much in the realm of speculative theories and hypotheses.[24] In the main, his object is to show that Vinča was a mining post concerned with the exploitation of cinnabar and ores which are to be found

[13] *Ibid.*

[19] *Ibid.*, p. 152.

[20] *Proceedings, London Cong. of Prehist. and Protohist. Sciences 1932* (1934), p. 207.

[21] It is of interest to note that on a previous occasion Vasić wrote about " influences of Ionian colonies, and of Greece itself, in sites of the Žuto Brdo type and time," *i.e.* his Iron Age (in reality advanced Bronze Age), cf. *Star.*, n.r g. V, (1910), pp. 31 ff., and especially p. 203.

[22] *Man, ibid.*, p. 197.

[23] *P. V. I.*

[24] *P. V. I* has the following contents: I. Cinnabar industry at Vinča, pp. 1–22; II. Cosmetics at Vinča, pp. 25–84; III. New aspects for the dating of Vinča, pp. 87–97; IV. Conclusisions: 1. The culture deposits, p. 101; 2. Houses and graves, pp. 101–2; 3. General character of the objects found, pp. 102–3; 4. The Ægean is the intermediary between Vinča and other cultural regions, pp. 103–4; 5. Mining wealth in the hinterland of Vinča, p. 104; 6. The colony and the colonists, cosmetics, economic bonds between Vinča and the Ægean, pp. 105–7; 7. The miners and the ethnic problem, pp. 107–8; 8. Religion at Vinča, social and political organization, pp. 108–9; 9. New problems and perspectives in prehistory, pp. 109–11; Addendum: I. Idols with perforations in prehistoric religion, pp. 118–40; II. Vinča and the hyperboreal myth, pp. 143–152.

nearby.[25]   The third stage—the final ?—is yet to be elabo-
rated.   Perhaps the forthcoming volume II of *Preistorijska
Vinča*, already announced to be in the press,[26] will have
accomplished this.

It is convenient at this point to consider the nature of the
site at Vinča.   Traditionally known as "Belo Brdo," [27] it is
situated upon the left bank of the Danube, approximately
15 km. eastward of Belgrade.   An indeterminate portion of
the station had been eroded by the waters of the Danube.
At this point the channel of the river, as suggested by the
position of the site of "Grad" at Starčevo [28] on the opposite
bank, appears to have been about the same as today.   At
Vinča, the height of the bank above the mean water level is
some 12 m., and the rise which marks the site measured 6 m.
to 8 m. in 1908.[29]   Inasmuch as the culture bearing deposits
range to the depth of 10.5 m. from the present ground level,[30]
it would seem that the elevation afforded natural protection
from seasonal inundations even at the very beginning of the
first settlement.[31]   As the debris subsequently accumulated,
this advantage was automatically increased.

The site rests upon a loess foundation which, prior to the
primeval occupation, was covered by a layer of humus some
0.5 m. thick.[32]   The quarternary formation is superimposed
upon fluviatile sands.   The lower limits of the culture bearing
deposits, represented by circular or oval pits (*bothroi* [33] or
Wohngruben [34]) cut through the aboriginal humus zone into
the loess, are sharply delineated and can be followed with
precision.   Below this level, however, the ground is archæo-

[25] *I.e.* at " Šuplja Stena," some 16 km. to the southwest of Vinča; cf. *ibid.*, pp. 4 ff.
[26] *R. I. E. B.*, p. 65.
[27] Cf. Vasić, M. M., *Star.* (1906), *ibid.*, p. 90.   The name means White Hill.
[28] Cf. Fewkes, V. J., Goldman, H., and Ehrich, R. W., *Bull. American School of Prehistoric Research No. 9* (1933), p. 35.   (Hereafter *Bull. A. S. P. R.*)
[29] *P. Z*, II, p. 23.
[30] *P. V. I, passim.*
[31] Cf. Vasić, *Star.* (1906), p. 90.
[32] *P. Z., ibid.*
[33] Vasić, *Annual Brit. School at Athens*, XIV (1907-8), p. 319.   (Hereafter *B. S. A.*)
[34] *P. Z., ibid.*, p. 26.

logically sterile.[35] Viewed from the Danube, the silhouette profile of "Belo Brdo" forms a curve which begins on the right hand side of the observer, rises gradually and progressively to produce a somewhat flattened summit, and then drops gently toward the opposite side. A similar outline, although necessarily an incomplete one, is to be seen from the direction of the east and also the northeast.[36]

The culture deposits of Vinča are 10.5 m. deep from the present surface level.[37] This measurement, apparently, is inclusive of the modern humus zone. In one instance only, that of the tomb with a "dromos" passage,[38] was this depth exceeded by 0.9 m.[39] The level characterized by culture pits constitutes the lowest niveau of the site, beginning at 9.1 m.,[40] at which plane the contours of these foundations of semi-subterranean dwellings stand in clear contrast to the yellow lœss.[41] The pits contain debris, ashes, cultural material, animal bones, etc.[42] Structurally, they are of the same character as those found in other Neolithic sites not only in this area, but virtually throughout the continent.[43] Above

[35] The stray mammoth tooth reported from Vinča, cf. Kanitz, F., *Das Königreich Serbien*, etc., I (Leipzig, 1904), p. 192, is not to be associated with the site under consideration.

[36] The extent of the site within the present bank, laterally with the course of the Danube, has not, apparently, been ascertained yet. At any rate, there is no record of it in the Vinča publications up to date. However, Vasić refers to the deposits as a " kegelförmige Erhöhung (Tell?) von ungefähr 35,000 *qm.* erhaltener Oberfläche" (*P. Z.*, II, p. 23).

[37] *P. V. I*, *passim*, and especially p. 97.

[38] *Ibid.*, p. 26.—The discovery of this tomb led Vasić to conclude: (1) that the large number of figurines and the frequent stray finds of human skull fragments prove that the people of Vinča buried immediately in the settlement; (2) that " numerous and heterogeneous statuettes were placed alongside the corpse " (*P. V. I*, p. 27). No furniture was found in the tomb with the " dromos," which contained nine skeletons. Apparently, the sepulcher was intact. Vasić mentions the remnants of wooden superstructure (*i.e.* roofing, cf. *op. cit.*, p. 102), and places the grave " chronologically and stratigraphically in the same period of time as the culture pits " (*ibid.*). However, more recently Vasić advances the view that the interments in the settlement at Vinča were cinerary (cf. *R. I. E. B.*, I, p. 69).

[39] *P. V. I*, p. 102.

[40] All vertical measurements used here must be understood as taken from the zero point established by the excavator in 1908, and coinciding with the otherwise applied " present surface."

[41] *Op. cit.*, p. 101.

[42] *Ibid.*

[43] They are, of course, not restricted to the Neolithic Age alone.

the pit level, remnants of rectangular dwellings begin, and continue as individual units through the rest of the deposits upward. The first named structures may be called huts, and the latter houses. No upper limit of the vertical distribution of the houses is given by Vasić, who, however, does speak of one example as high as 2 m. from his horizontal zero point.[44] The stratigraphically deepest occurrences of such structures were recorded at as much as 9.3 m.[45] It is not stated whether in these particular instances the foundations rested upon the lœss or the pit level. The tectonic contrast between the hut which depended upon a rounded or oval sub-pit defining its originally semi-subterranean nature, and the house, is considerable. The pit type may be likened to the hogan of the Navaho tribe of the North American Southwest. At Vinča, the wattle and daub principle was applied insofar as the superstructure was concerned. The houses, on the other hand, were of rectangular ground plan, with walls constructed of posts, onto which, both inside and outside, clay plaster was attached, the whole wall attaining the probable thickness of 0.15 m. to 0.3 m.[46] Artificially prepared floors of a more or less level plane were an important feature. Yet, subsidiary pits were sometimes utilized either within the houses or in a close association with them.[47] The remains of these houses, as they have been preserved in the deposits subsequent to their collapse, resemble the *ploščadki* of the Black Earth belt. Typologically, there is a marked difference between the two types of dwellings at Vinča. However, the deposits within which both occur, that is "die unteren Strata dieser Schicht bis zur ihrer Höhe von 4.5 *m.* sind als ein mehr oder weniger einheitliches Ganze zu betrachten" [48] and "as other remains prove, the change in the form of the ground plan took place gradually." [49]

[44] *Op. cit.*, p. 10; cf. text fig. 6 on p. 11, *ibid.* In the same work plans of other houses appear in t. f. 7, 8 (p. 11), 17 (p. 14); and plates III–VIII show photographs of exposed houses.

[45] *Ibid.*, p. 101.

[46] *Ibid.*, p. 10.

[47] See *ibid.*, Pls. VI, VII, and VIII.

[48] *P. Z*, III, p. 129.

[49] Vasić, *B. S. A.*, *ibid.*

This 4.5 m. thickness of the lower levels (*i.e.* up to the 5.5 m. horizon below the ground zero line), Childe considers to represent his (Neolithic) Vinča I.[50]   In Menghin's conception "die älteste Kultur von Vinča," again (Neolithic) Vinča I, "kann etwa von der Basis bis 5.6 m. angesetzt werden, wo die erste Spiralmuster beginnen." [51]   And in the same sense, Nestor has subsequently applied the equation "Vinča I = Turdas I-Kultur." [52]   Childe's Vinča II deposits, still Neolithic, superimposed over the 5.5 m. level and amounting in thickness to 1.5 m., reach as high as 4 m. below the surface.[53] Menghin also recognizes (Neolithic) Vinča II, but gives no specific limit to its vertical termination.[54]   According to Childe's interpretation, the appearance of Bronze Age ware begins at the level of 4 m. below the surface.[55]   This delineation is, of course, a provisional one, and not without an arbitrary stigma; it may, however, be accepted *per se*, especially since the excavator himself offers no direct data on this point.   Indeed, none of Vasić's writings which deal with Vinča, contain any schemes comparable to those just mentioned.   Occasionally, a reference is made by him to "lower, middle, and upper strata," [56] but none of these instances can be taken in the sense of the "chronological trinity" with which one meets all too frequently.   It is in one publication only that Vasić speaks of "thinner levels." [57]   Certainly, Vasić has consistently abstained from applying the often convenient, but not always unambiguous, system of a numerical division of strata.   On the other hand, his general interpretation, and specifically his erratic datings, inevitably benefited by freedom from a classificatory stratigraphic differentiation.

[50] *The Danube in Prehistory* (Oxford, 1929), p. 26.   (Hereafter *Danube*.)

[51] *Weltgeschichte der Steinzeit* (Wien, 1931), p. 353.   (Hereafter *Weltgeschichte*.) Cf., however, Vasić, *P. Z.*, II, p. 31: "Die Spirale kam for in der Tiefe von 2.5 bis 6.8 *m.*"

[52] *22. Bericht R.-G.K.* (1932), pp. 33 ff.   (Cf., however, the author's cautious remark in respect to the dual division of Vinča, *l. c.*, p. 35.)

[53] *Danube, ibid.*, p. 27.   (Cf. however, p. 65, note 1, for Childe's uncertainty.)

[54] *Weltgeschichte*, pp. 353–4: "Vinča II stelle ich bereits zu den bandkeramischen Kulturen."

[55] *Danube, ibid.*

[56] *B. S. A., ibid., passim.*

[57] *P. V. I*, p. 97.

Among the students of Danubian archæology a concensus of opinion prevails which accepts Vinča, at least insofar as its deposits below the 5.5 m. level from the present surface are concerned, as representing the oldest Neolithic development at the site.[58] Of the Yugoslav specialists, it is Grbić who compares certain Neolithic or "Eneolithic" finds from the Morava Valley area with Vinča.[59] Whether or not it is permissible to distinguish Neolithic Vinča I and II stratigraphically before its excavator has presented a full description of the deposits and an exhaustive analysis of the material, is, of course, open to conjecture. The demarcation line between the two, must, necessarily, be an arbitrary one as long as it is conceived to coincide with the level of 5.5 m. (or 5.6 m.) below the surface. In a settlement in which successive occupation is documented by a layer of deposits 10.5 m. thick, and in which the erection of houses above the oldest pits inevitably produced fluctuation in the horizontal planes, complicated stratigraphic conditions are the rule. At Vinča, the termini of the recognizable levels are defined sharply only in the cases of the individual pits and houses. While these should be horizontally alignable into "occupational floors or niveaus," the excavations up to date have not established such a phenomenon. Thus far, Vasić has not presented a comprehensive account of all the structural features, the number of dwellings which he excavated, nor their horizontal and stratigraphic distributions.[60] Yet, from his preliminary reports, others have conjured up Vinča I and Vinča II.[61]

"The culture of Vinča II," holds Childe, "is largely a continuation of that of Vinča I." [62] And Menghin places

[58] Frankfort (Studies, II [1927]), Childe (Danube, ibid.), Menghin (Weltgeschichte, ibid.). There are other citable instances, too numerous to exhaust here.

[59] I.e. those of Lipovac, cf. Godiš., XXXIX (1930), p. 197, and " Pločnik," cf. his Pločnik, etc., (Beograd, 1929), p. 18, as well as those of the unexcavated site at Resnik Kragujevački, near Kragujevac (personal information, season 1931). For Grbić's review of P. V. I, cf. Star., 3rd ser., 8/9 (1933-34), pp. 322 ff.

[60] A chart showing the profile revealed by the excavations of 1908 appears in P. Z., II, pl. 7, Fig. a, and Figs. b and c, on the same plate, illustrate the ground plan and section of the pits found during that season. Cf. also note 37, supra. These, however, do not cover the total.

[61] The chief source was found in P. Z., II and III.

[62] Danube, p. 68.

Vinča I within his "ostmediterrane Dorfkultur" or "Kreis." [63]
Admitting that such a placement "erscheint ein Wagnis" [64]
the author is nevertheless convinced that alongside other
cultural affinities, Vinča stands "weitaus am nähsten" to the
East Mediterranean.[65] Menghin's Vinča II, as we have
seen,[66] belongs to the "bandkeramischen Kulturen," [67] and
more specifically to the "serbische oder Jablanicagruppe" [68]
as a part of his "südbandkeramische Kultur." [69]

Truly, the bulk of the material found at Vinča has not
been completely analyzed and published by the excavator as
yet. Nor are his field explorations completed. Vasić's
account of the finds at Vinča which antedate his first campaign
at the site in 1908 [70] and his writings since that time [71]
certainly have not presented an exhaustive study. There is,
in reality, no thorough account of the pottery. While it is
true that only a portion of the site has been excavated thus
far, and that the exploration continues, the section as estab-
lished by the end of the season of 1931 equaled 12,600 cubic
meters.[72] This should have afforded ample sampling with
which to present a system of at least the ceramic development.

[63] *Weltgeschichte*, p. 353.
[64] *Ibid.*
[65] *Ibid.*
[66] Note 54, *supra.*
[67] *Op. cit.*, pp. 353–4, and 369 ff.
[68] *Ibid.*, p. 372.
[69] *Ibid.*
[70] *Glas.*, LXX, pp. 163 ff. (dealing with privately collected material from Vinča which was tendered to the National Museum at Belgrade; the site is compared there with " Čaršija," " Mali Drum," " Kremenite Njive," and " Jablanica "); *Star.* (1906), pp. 89–127 (devoted solely to Vinča, and again based upon privately collected material); *Memnon*, I, 2 (1907), pp. 177–187 (a review).
[71] *B. S. A.*, *ibid.*, pp. 318–342 (in which, insofar as Vinča is concerned, the previous writings are drawn upon, and the first excavations are partially utilized); *Godiš.*, XXII, pp. 162 ff. (as a part of the official report on the activities of the National Museum in 1908); *P. Z.*, II, pp. 23–39 (the most important article in this regard, from which others have obtained the basis of their treatments); *P. Z.*, III, pp. 126–132 (concerns itself with the dating and extraterritorial relationships of the site); *Man*, XXX, pp. 197–200 (a brief article in the nature of a field report); *P. V. I*, pp. XIII +159, 149 ills., *i.e.* 19 in the text, the rest on XXXVIII plates, of which the last four are colored (as may be seen from the contents given in note 24, *supra*, very little space is devoted to pottery); *R. I. E. B.*, I, pp. 65–73 (deals with Vinča as an Ionian colony).
[72] *P. V. I*, pp. XIII and XI.

Instead, since 1932, the distinguished excavator has devoted much of his pen to considerations, theories, and hypotheses [73] which have no practical bearing on the real cultural development at Vinča.[74]

As must be apparent from the foregoing, the division of Neolithic Vinča into I and II is not without ambiguity. Naturally, the classificatory differentiation should be advanced by the excavator. Unfortunately, his latest interpretations have only confused the issue. At the moment, there seems to be no remedy for the dual separation. That the *line* between the two is not a tangible reality must be admitted. The upper portion of the Vinča I deposits, and conversely, the lower limits of the Vinča II deposits, should be expected to be fused into somewhat of an intermediate zone. Vasić, as already mentioned,[75] sometimes referred to lower, middle, and upper levels, without, however, any specific distinguishing indeces. Therefore, it is not possible to separate the deposits of Vinča, whether Neolithic or later, into dependable divisions. At the same time it is true that the designation of Vinča I and II, insofar as its Neolithic Age is concerned, offers a valuable aid in the synchronism of the culture history in a large area which covers much of Central and at least a part of Southeastern Europe. Indeed, as Childe justly points out, Vinča is the sole standard for a provisional classification.[76]

That Vinča is first of all a Neolithic site is proved by the very material it contains. This represents a culture complex which was initially introduced into this region from outside. Whether it is called Danubian [77] or Anatolio-Aegean,[78] the traces of its original diffusion are still unknown. Yet the weight of evidence points to the direction of the Southeast, a somewhat vague concept in European archæology. Perhaps Hither Asia, in itself not a very clear cut geographic connota-

[73] Cf. note 24, *supra*, and *R. I. E. B.*, I, pp. 65 ff.
[74] Cf. Grbić's review cited in note 59, *supra*.
[75] Cf. note 56, *supra*.
[76] *Danube*, p. 26.
[77] Childe, *ib:d.*, pp. 26 ff.
[78] Menghin, *ibid.*, p. 356.

tion, or possibly Anatolia, may be postulated as the original area whence started the cultural and ethnic movements which were eventually responsible for the introduction of the primary Neolithic into Southeastern Europe. This view is brought out in a convincing manner by Childe [79] in his critique of Frankfort's theory of Danubean influences in the Ægean.[80] Whether or not it is possible to distinguish a Copper or Chalcolithic period at Vinča is a vulnerable point. Local metallurgy, the sole dependable criterion which should decide the issue, cannot be proved as an integral constituent within the cultural capital of Vinča I and II. Vasić's arguments in this regard are not convincing.[81] Stray metal objects do appear, to be sure, as far down in the deposits as 8.1 m., but they are rare.[82] Their presence is explainable as being due to trade (*i.e.* imports from outside), or perhaps to chance production at the site. In either case, these specimens have not affected any noticeable influence upon the prevailing stamp of cultural expression. It is a methodological fallacy when an attempt is made to establish an age of metal upon such inadequate evidence.

Turning our attention once more in the direction of the *beginnings* of Vinča, our search for possible antecedants insofar as the earlier stages of local culture history are concerned, meets first with a pronounced *hiatus*. Paradoxically enough, our inquiry at once begins and ends, quite abruptly, with the Aurignacian phase of the Upper Palæolithic Age. The existing data on this point are indeed far from satisfactory. The following is the historically first reference which has a direct bearing on our task: "Des pointes et des silex aurignaciens viennent aussi de caverns de la region de Belgrade." [83] There is no description of these specimens, no names of the caves concerned, nor is it stated where the artifacts are now deposited, or how many have been found. Furthermore, one

[79] *Jour. Hellen. Studies*, L (1930), pp. 255 ff.   (Hereafter *J. H. S.*)
[80] *Studies*, II, pp. 24 ff.
[81] *P. V. I*, pp. 1–22, 34 ff., and 103 ff.
[82] Vasić, *Man*, XXX, p. 200.
[83] Breuil, H., *L'Anthropologie*, XXXIII (1923), p. 333.

looks in vain for at least a mention of the circumstances under which this material was collected. Nor is the nature of the caves and their floors given. However, the reference here quoted has been used by other students,[54] among whom there is an agreement that typologically, as ascertained by Breuil,[55] the material in question represents the Aurignacian phase. Whether or not actual deposits bearing this industry do exist in the caves around Belgrade, remains obscure. There are no suggestions whatsoever of Solutrean, Magdalenian, or Mesolithic remains here. The inferences of Palæolithic man in the region eastward of Niš, which in point of geography is contiguous with the hinterland of Vinča, are based purely on palæontological evidence,[56] and have been refuted.[57] The status of the *hiatus*, which is so clearly demonstrated elsewhere in the Danube Basin, is likewise implied in the region which forms the southeastern portion of its middle subdivision. The postulation, therefore, that the Neolithic Age in this region, in its beginning at any rate, is to be explained as a new ethnic and cultural arrival, must be reiterated.

Aside from Vinča, the series of Neolithic sites distributed to the south and east of it, strongly suggest an area of homogeneous development. Both on geographic and on culture-historic grounds, this territory may be spoken of as the Moravo-Danubian area. In extent it corresponds to the drainage system of the river Morava, which through its Binačka, Southern, and Western branches collects much of

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[54] *I.e.* MacCurdy, G. G., *Human Origins*, I (New York, 1924), Fig. 83 on p. 168, and p. 170 (without a literary citation—cf. Skutil, J., *Eiszeit und Urgeschichte*, V [1929], note 43, who also qualifies MacCurdy's plotting of the " four caves near Belgrade " [*l.c.*, Fig. 83] as " wohl schematisch " [*op. cit.*, note 45]; Obermeier, H., *Reallexikon der Vorgeschichte*, VI (Berlin, 1925), p. 170; Skutil, J., *op. cit.*, p. 27; Childe, V. G., *Danube*, p. 12; and more recently, Skutil, J., *Bull. Soc. Préh. Fr.*, XXVIII (1931), pp. 234 ff., again refers to the " sporadic, but indubitably Aurignacian finds from several caverns in the environs of Belgrade, brought to attention by Breuil."

[55] *Loc. cit.*

[56] *Bull. A. S. P. R.*, No. 9, p. 28, note 24.

[57] Cf. Menghin, O., *Wiener Präh. Zeit.*, II (1915), pp. 128 ff., who, speaking of the Jelašnica etc. caves, states: " . . . wenigstens lasst sich aus ihnen nichts Sicheres entnehmen . . ."; and Skutil, *Eiszeit u. Urgesch.*, *ibid.*, p. 28: " Die Datierung einer dieser Lokalitaten als paläolithisch sei ganz unbegründet."

the waters of northeastern Yugoslavia.   In nature of soils,
climate, and other economic factors, as well as in physi-
ography, the Moravo-Danubian area is a unit.   It is traceable
as such throughout history, beginning with the Neolithic Age.
Its spatial limitations fall within an inverted curvilinear
triangle, of which only one side, *i.e.* that coinciding with the
course of the Danube, is sharp.   The northeastern point is
located at the confluence of the Kolubara with the Sava,
near Belgrade; the vertex lies in the Morava-Vardar divide,
and the northeastern angle is given by the Tuman spur and
the Danube, near Golubac.   This triangle occupies the
northeastern portion of the anthropogeographical concept
advanced by Cvijić, who defined it as the Central or Morava-
Vardar area.[88]   The main body of the Morava Valley system
corresponds to the Morava or Šumadija region of Cvijić's
subdivision.[89]   The topography of our area represents a
dendritic pattern of valleys which accommodate the numerous
tributaries of the branches of the Morava.   These are inter-
spaced by uplands and mountains.   The predominant orienta-
tion of these valleys is in the general direction of south-north,
to a lesser degree west-east, and least of all east-west.   The
main corridor stretches from the Morava-Vardar divide in a
north-north-westerly direction towards the Danube.   There
is no abrupt break between the drainage systems of the
Morava and the Vardar.   On the contrary, a moderate
relief spans the two, namely through the region known as
Žegligovo, and south of that the Skoplje Basin can be reached
comfortably.   The mountain chain which lines the Moravo-
Danubian area on the east may be crossed by way of the
Nišava river, whereby an entry into the drainage of the Iskar
(in Bulgaria) is gained.   The Sičevo chasm, a formidable
barrier, can be circumvented.   Other connections are avail-
able further north and offer egress either to the valley of the
Timok, or into regions eastward of the Iron Gate.[90]   The

[88] Cvijić, J., *Osnove*, etc., I, *S. K. A.*, pos. izd., kn. 17 (Beograd, 1906), p. 61.
[89] *Op. cit.*, p. 62.
[90] *Ibid.*, p. 69.

western mountain boundaries of our area likewise provide
means of communication.

Whatever the conditions may have been in aboriginal
Neolithic times, the body of the valley was early settled.
Apparently its climate and soils were then attractive to
agriculture and stock raising. It is of interest to note that
today these two industries, together with horticulture, are
the basis of local economy. And as far as written records
offer evidence, this seems to have been the case from the time
of the Roman rule. Certainly the archæological remains,
insofar as known, point to a similar economic status (excepting
tree culture) from the Neolithic Age onward.

Among the sites which are illustrative of close analogies
with Vinča, not only with its period II, but also to a greater
or lesser extent with period I, the following have been either
partially excavated or sounded:

1. "Čaršija," near Ripanj; [91]
2. "Mali Drum," near Popović; [92]
3. "Kremenite Njive," at Barajevo; [93]
4. "Jablanica," at Medjulužje; [94]
5. "Dizaljka," at Lipovac, near Arandjelovac; [95]
6. "Pločnik," between Prokuplje and Kuršumlija; [96]
7. "Velika Humska Čuka," near Niš; [97]

[91] Vasić, Godiš., XVIII (1904), pp. 236 ff., and Glas, LXX (1906), pp. 165 ff.
[92] Vasić, Godiš., op. cit, and Glas, ibid.
[93] Valtrović, M., Star., VI, 3 (1889), p. 96; Žujevic, J. M., and Valtrović, M., Star., VIII, 1/2 (1891), pp. 1 ff.; Vasić, op. cit.
[94] Vasić, Archiv f. Anthrop., XXVII, 4 (1902), pp. 517 ff.
[95] Grbić, M., Godiš., XXXIX (1930), p. 197, and Fewkes, op. cit., p. 26. A brief sounding was made in this site by the University Museum of Philadelphia, Pa., and the Peabody Museum of Harvard University Joint Expedition in 1931.
[96] Grbić, M., Pločnik, etc. (Beograd, 1929); the author dates this site as of the Late Neolithic or Eneolithic Age.
[97] Partially excavated by the National Museum of Belgrade in 1934, under the direction of Dr. Grbić. In his letter of February 20, 1935, Dr. Grbić has kindly furnished me with the following information regarding his finds: "There are stray Neolithic axes, but no Neolithic deposits. The culture level is of the Bronze Age, and has new types of ceramics and decoration, among which painted pottery, black on white, is present. The site is of the Early Bronze Age date. There are also Roman and Byzantine antiquities, and Slavic pits." (Free translation.) In my opinion, which is based upon the material previously found at the site and now deposited in the Museum at Niš, Neolithic ceramic traits comparable to Vinča are also present. The

8. "Gradac," above Zlokučane, near Leskovac; [98]
9. "Gumnište ("Barak")—Čukar," at Pavlovce near the head-waters of the Southern Morava.[99]

The Niš Museum, a young, but very active institution, has in the course of the past two years recorded a number of sites in various parts of the Morava Valley. The American Expeditions of 1932, 1933, and 1934, all in charge of the present writer, have participated in this work.[100] Through the kindness of the Niš Museum, and also the Negotin (Krajina) Museum, the Expedition of 1933 and the 1934 American School of Prehistoric Research, greatly benefited in their work in northeastern Yugoslavia. Out of the combined efforts, and incorporating the subsequent finds of the Niš Museum which fall within the area under discussion,[101] the following sites, again comparable in their material contents to Vinča, may be listed:

1. "Kavolak," at Prokuplje.[102] Among the material found at this site are represented the barbotine and painted classes of pottery which are so characteristic at "Grad," Starčevo,[103] and which are not uncommon in the lower levels at Vinča.[104] Thus far, the Neolithic material from

excavations of 1934, restricted as they were in areal extent, are not necessarily conclusive insofar as the total deposits are concerned. It is possible, of course, that the site may have been only a transient one in Neolithic times, and that the layer which should identify it may have an irregular horizontal distribution.

   [98] Vasić, *Glas*, LXXXVI (1911), pp. 97 ff.; the author dates this site as of the La Tène phase of the Iron Age.

   [99] Fewkes, *Bull. A. S. P. R.*, No. 10 (1934), pp. 42 ff.

   [100] *Bull. A. S. P. R.*, No. 9 (1932), pp. 17 ff., No. 10 (1934), pp. 29 ff., and No. 11 (1935), pp. 10 ff.

   [101] With the kind permission of the Niš Museum, which is hereby gratefully acknowledged.

   [102] Cf. *Bull. A. S. P. R.*, No. 11 (1935), pp. 11–12.

   [103] *Bull. A. S. P. R.*, No. 9 (1933), pp. 44 ff.

   [104] *P. V. I*, pp. 90 ff., and *Bull.* No. 9, *ibid.*, p. 48.—Vasić compares the barbotine ware with the "striated" sherds from the tumba at Vardarovca in Greek Macedonia (cf. *P. V. I*, p. 91, note 20). In my opinion, such a comparison is not justified, inasmuch as at Vardarovca "the decoration is made with a toothed instrument producing shallow sweeping parallel lines, moving in different directions . . ." (Heurtley, W. A., *B. S. A.*, XXVII [1925–26], p. 16). There is no additional application of paste to enhance the relief effect which is such a typical element at Starčevo, and which is certainly apparent in the Vinča parallels (cf. *P. V. I*, Pl. XXIX, ills. no. 132 a, and b, and no. 133).

"Kavolak" includes the two classes of pottery already mentioned, one crude figurine of baked clay, celts of the shoe-last type, and notched flat pebbles.[105] .

2. "Kovanluk," at Malče, near Niš.   The Neolithic material contains: barbotine, incised (bands filled with indentations or short cuts), fluted, and burnished wares; flat discoidal pebbles with notches on their long sides.[106]

3. "Jelašnica," near Niška Banja.[107]   Only the incised ware appears among the Neolithic material collected here.

4. "Šetka," near Ražanj.   The Neolithic representatives at this site are: incised (filled bands), fluted, and burnish-decorated wares, and libation tables (some with incised decoration).[108]

5. "Osmakovo," near Pirot.   The Neolithic material includes: barbotine, incised (filled bands), fluted, and burnished wares; libation tables (some with incised decoration); shoe-last celts.[109]

6. "Tumba," at Kalna, near Pirot.   Here the Neolithic fluted and burnished wares are represented.[110]

The sites at Bunar, Donja Glama, Kravlje, Soko Banja, Šanac, and Vrmdja, from all of which sample material has been collected,[111] each contain some examples of Neolithic analogies with Vinča.

Other instances of similar analogies, of which some are only provisionally so considered, are known from the following:

1. "Šuplja Stena," near Belgrade.   This is a Neolithic (incised material) and later site located upon the summit of the hill which contains the cinnabar galleries thought by Vasić to have been exploited by the people of Vinča.[112]

[105] Deposited in the Museum at Niš.
[106] Deposited in the Museum at Niš.
[107] I.e. the cave of "Crkvine" (information from Niš Museum, letter of June 11, 1935)—Material deposited in the Museum at Niš.
[108] Deposited in the Museum at Niš.
[109] Deposited in the Museum at Niš.
[110] Deposited in the Museum at Niš.
[111] Deposited in the Museum at Niš.
[112] P. V. I, pp. 4 ff.; the deposits in question are dismissed by Vasić as a " poor prehistoric settlement " (l.c., p. 6).

2. "Avala," near Belgrade; [113]
3. The vicinity of Rudnik; [114]
4. The cave at Petnica; [115]
5. The vicinity of Požarevac; [116]
6. The village of Resnik Kragujevački, near Kragujevac.[117]

The enumerated instances of analogies with Vinča do not, I am fully aware, exhaust the field under discussion. The geographic distribution of the relevant sites falls within a belt which appends onto the Danube in the northwestern periphery of the area, and from there stretches in the direction of the southeast. The bank of the Danube itself, at least below Vinča and as far as Golubac is still without comparable deposits,[118] although sites of the Bronze Age are known.[119] On the northern side of the Danube, *i.e.* in the Banat, several Neolithic stations related to Vinča have been explored.[120] In Roumania, sites of the Turdas group, as defined by Nestor [121] afford a continuous tracing of like development into Siebenbürgen and thence on the eastern side of the Transylvanian Alps once more to the Danube.[122] In Greater Walachia, according to Nestor, the sites on the bank of this river have no Vinča traits.[123] Presumably, the same is true of the opposite side in Bulgaria, where the Boian A development is dominant.[124] On the other hand, in northwestern Bulgaria, and in the Ključ and Krajina regions of northeastern Yugoslavia, close comparisons with Vinča are encountered again,

[113] Cf. Hofmann, R., *M. A. G. W.*, XVI (1886), pp. [39] ff.
[114] Cf. Trojanović, S., *Star.*, VII, 4 (1890), pp. 101 ff., and IX, 1 (1892), pp. 1 ff.
[115] Cf. Jovanović, Dj. P., *Star.*, IX, 2 (1892), pp. 41 ff.
[116] Cf. Jovanović, Dj. P., *Star.*, IX, 3 (1892), pp. 81 ff.
[117] Personal information from Dr. Grbić, season 1931. Cf. note 59, *supra*.
[118] Between Golubac and the Iron Gate the oldest remains thus far ascertained are of the Roman period; cf. Fewkes, *Bull. A. S. P. R.*, No. 10 (1934), pp. 33 ff.
[119] Cf. Vasić, *Star.*, V (1910), pl. 1, which contains a map giving their distribution.
[120] Karapandžić, D. Dj., *Star.*, 3rd ser., I (1922), pp. 151 ff.; Menghin, O., *Star.*, 3rd ser., IV (1926–27), pp. 15 ff. (and literature given therein); Fewkes, Goldman, Ehrich, *Bull. A. S. P. R.*, No. 9 (1933), pp. 33 ff.
[121] *22. Ber. R.-G. K., ibid.*, pp. 33 ff.
[122] *I.e.* Ostrovul Korbului and Ostrovul Mare, cf. *ibid.*, p. 34.
[123] *Ibid.*
[124] *Op. cit.*, pp. 34–35.

Legend:

B Belgrade

Č "Čaršija" (Ripanj)

Go Golubac

Gr "Gradac" (Zlokučane)

IG Iron Gate

Ka "Kavolak" (Prokuplje)

Kč Region of Ključ

KNj "Kremenite Njive" (Barajevo)

Kr Kragujevac

L Lipovac ("Dizaljka")

MD "Mali Drum" (Popović)

Ne Negotin ("Kusjak")

Nš Niš ("Kovanluk", and "Šetka")

NB Niška Banja ("Jelašnica")

Pa Pavlovce ("Gumnište")

Pi Pirot ("Osmakovo", and "Tumba")

Pl "Pločnik"

Po Požarevac

R Rudnik

Sk Skoplje

St Starčevo ("Grad")

ŠS "Šuplja Stena"

V Vinča ("Belo Brdo")

VHČ "Velika Humska Čuka".
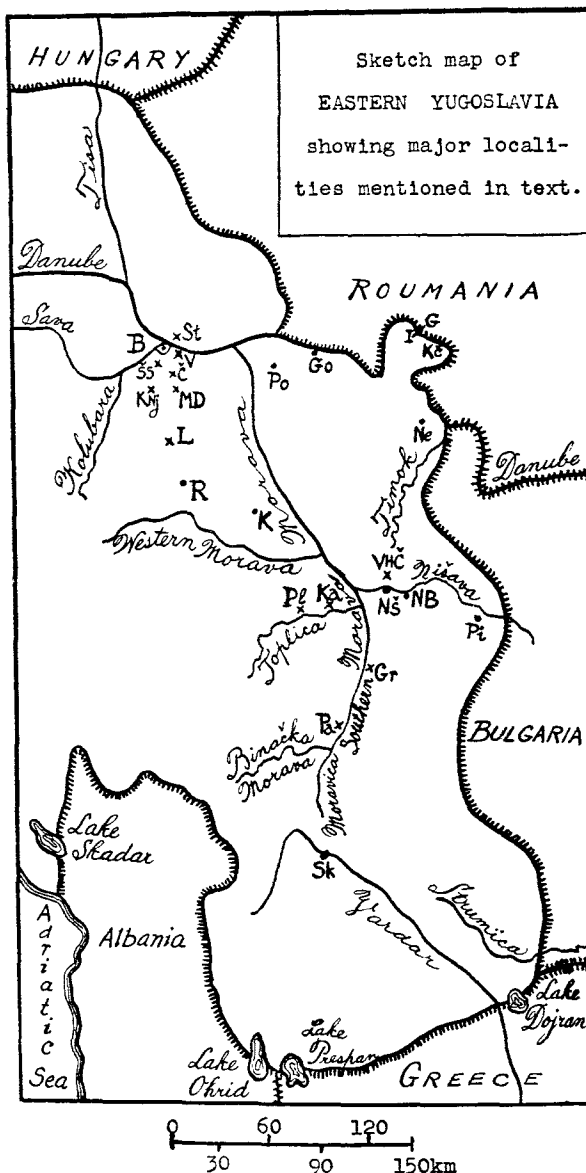
Sketch map of Eastern Yugoslavia.

although Starčevo characteristics are especially pronounced.[125]
Perhaps the largest and richest known Neolithic site between
the Iron Gate and the river Timok is that of "Obala" above
Korbovo, opposite the island which bears the name of
Korbului in Roumanian.[126]   The distribution of the Ključ
and Krajina stations seems to be restricted to the bank of
the Danube.[127]   The geographically nearest analogies towards
the south are to be found off the Pirot Basin and the valley of
the Nišava.[128]   We have seen that communicable passes
exist between the Moravo-Danubian area and the regions
eastward of the Iron Gate.   At the present time there is
neither evidence to show nor even suggest that these were
actually utilized in Neolithic times.

If one is to seek possible routes by which Neolithic
cultural traffic may have moved in these parts of the Balkans,
serious difficulties stand in the way.   The greatest of these
are the numerous regional lacunæ insofar as archaeological
knowledge is concerned.   The Morava-Vardar valley, and
especially its stretch between Djevdjelia and the Skoplje
Basin is perhaps the most outstanding example in point.[129]
Nor does the valley of the Ibar, farther to the west, which
leads into Kosovo, and which is deemed to be a possible
route by Childe,[130] admit of acceptance.   Towards the west
and northwest, the Drina, Sava, Bosna, Drava, Tisa and the
Danube itself accommodate communication, which appears
to have been utilized from the Neolithic times onward.[131]
The situation, no doubt, is the more complicated since it is
apparent that successive waves of diffusion have taken
place.[132]   Still, it is to be expected that the systematic work

[125] Fewkes, *Bull. A. S. P. R.*, No. 10 (1934), pp. 35 ff.
[126] Cf. note 122, *supra*.
[127] Fewkes, *ibid.*, p. 38.
[128] Cf. notes 109 and 110, *supra*.
[129] Fewkes, *ibid.*, p. 44.
[130] *Danube, ibid.*, p. 2.
[131] Thus explaining the presence of such sites as " Butmir," " Debelo Brdo,"
" Donji Klakar," " Novi Šeher," " Donja Mahala," etc., in the westerly direction,
and analogous sites along the Tisa.
[132] Childe, *J. H. S., ibid.*, p. 261.

now in progress in Yugoslavia and the adjacent countries will do much towards the solution of the existing deficiencies.

To recapitulate: Vinča is a Neolithic settlement representing perhaps the highest cultural attainment in a large area which may be defined respectively as the eastern extremity of the Middle Danubian Basin and the western extremity of its Lower division. The primary diffusion responsible for its introduction to Europe seems to have come from the direction of the southeast, apparently from regions beyond the Bosporus and Hellespont. The Moravo-Danubian area, an integral part of the Middle Danubian Basin, presents a geographical unit which admits of regional treatment. Whether Vinča was actually its cultural center,[133] is, I think, a difficult task to decide, and one which is of no great moment in itself. What is really important and seriously needed is to deal with the evidence before us in the light which is justified first of all by the nature of the deposits, secondly by the cultural development which they document, and thirdly by germane correlations with parallel sites. Vinča should be *the* real standard of the southern Danubian Neolithic.

SELECTED BIBLIOGRAPHY

BREUIL, H., Notes de voyage paléolithique en Europe Centrale, L'Anthropologie, XXXIII (1923), pp. 323 ff.

CHILDE, V. G., The Danube in prehistory (Oxford, 1929). New views on the relations of the Ægean and the North Balkans, Journal of Hellenic Studies, L (1930), pp. 256 ff.

CVIJIĆ, J., Osnove za geografiju i geologiju Makedonije i Stare Srbije, Srpska Kraljevska Akademija, pos. izd. kn. 17 (Beograd, 1906).

FEWKES, V. J., Report on the school, season 1933, Bulletin of the American School of Prehistoric Research, No. 10 (1934), pp. 21 ff. Reconnaissance in Yugoslavia, season 1933, Bull. A. S. P. R., No. 10 (1934), pp. 29 ff. Explorations in Czechoslovakia and Yugoslavia, season 1934, Bull. A. S. P. R., No. 11 (1935), pp. 7 ff. Neolithic sites in the Moravo-Danubian area (Eastern Yugoslavia), MS. now ready for the press, to appear in American Journal of Archæology, XXXIX (1935).

FEWKES, V. J., GOLDMAN, H., AND EHRICH, R. W., Reconnaissance in Yugoslavia, season 1932, Bull. A. S. P. R., No. 9 (1933), pp. 17 ff. Excavations at Starčevo, Yugoslavia, season 1932. Bull. A. S. P. R., No. 9 (1933), pp. 33 ff.

FRANKFORT, H., Studies in early pottery of the Near East. II. Asia, Europe and the

[133] As Vasić at one time thought (cf. *P. V. I.* p. 110), but immediately weakened by questioning the placement of " Pločnik " and " Gradac " within the narrower area of Vinča's influence (*ibid.*).

Ægean, and their earliest interrelations, Royal Anthropological Institute of Great Britain and Ireland, occasional papers, No. 8 (1927).

GRBIĆ, M., Historičko-Umetnički Muzej u 1929 god., Godišnjak Srpske Kraljevske Akademije, XXXIX (1930), pp. 194 ff. Pločnik. Eine prähistorische Ansiedlung aus der Kupferzeit (Beograd, 1929). Review of Vasić, M. M., Preistorijska Vinča I, Starinar, 3rd ser., VIII–IX (1933–1934), pp. 322 ff. Historičko-Umetnički Muzej u 1933 god., Godišnjak S. K. A., XLII (1934), pp. 258 ff.

HEURTLEY, W. A., Report on excavations at the toumba and tables of Vardaroftsa, Macedonia, 1925, 1926. Part I. The toumba, Annual of the British School at Athens, XXVII (1925–1926), pp. 1 ff.

HOFMANN, R., Prähistorische Funde aus dem Quecksilberbergen " Avala " in Serbien, Mitteilungen der Anthropologischen Gesellschaft in Wien, XVI (1886), pp. [39], ff.

JOVANOVIĆ, DJ. P., Petnička pećina i preistorijsko selište iz neolitskog doba, Starinar, IX, 2 (1892), pp. 41 ff. Kamena orudja iz preistorijskog doba u okolini Niša, Valjeva i Požarevca, Starinar, IX, 3 (1892), pp. 81 ff.

KANITZ, F., Das Konigreich Serbien und das Serbenvolk von der Römerzeit bis zur Gegenwart, Vol. I (Leipzig, 1904).

KARAPANDŽIĆ, D. DJ., Aradac, Starinar, 3rd ser., I (1922), pp. 151 ff.

MacCURDY, G. G., Human origins, I (New York, 1926).

MENGHIN, O., Spuren des Paläolithikums in den nördlichen Balkanländern, Wiener Prähistorische Zeitschrift, II (1915), pp. 128 ff. Ka preistoriji Vršačke oblasti, Starinar, 3rd ser., IV (1928), pp. 15 ff. Weltgeschichte der Steinzeit (Wien, 1931).

NESTOR, J., Der Stand der Vorgeschichtsforschung in Rumänien, 22. Bericht, Romisch-Germanische Kommission, D. A. I. (1932), pp. 11 ff.

OBERMEIER, H., Jugoslavien—Paläolithikum, Reallexikon der Vorgeschichte, ed. Ebert, M., VI (1925), pp. 170 ff.

SKUTIL, J., Das Paläolithikum des Balkan, Eiszeit und Urgeschichte, V, 1 and 2 (1928), pp. 24 ff. L'époque quarternaire dans les Balkans, Bulletin de la Société Préhistorique Française, XXXVIII (1931), pp. 234 ff.

TROJANOVIĆ, S., Preistorijske starine iz Rudničkog okruga, Starinar, VII, 4 (1890), pp. 101 ff.

VALTROVIĆ, M., Ostaci preistorijske naseobine u Barajevu, Starinar, VI, 3 (1889), p. 96.

VASIĆ (sometimes Vassits), M. M., Die neolithische Station Jablanica bei Medjulužje in Serbien, Archiv für Anthropologie, XXVII, 4 (1902), pp. 517 ff. Izveštaj o iskopavanjima preistorijskih starina u 1904. god., Godišnjak S. K. A., XVIII (1904), pp. 236 ff. Izveštaj o radu u archeološkom odeljenju Narodnoga Muzeja u god. 1905., Godišnjak S. K. A., XIX (1905), pp. 241 ff. Narodni Muzej, Godišnjak S. K. A., XX (1906), pp. 201 ff. Preistorijska votivna grivna i uticaji mikenske kulture u Srbiji, Starinar, n.r.g. I, 1 (1906), pp. 1 ff. Nekoliki preistorijski nalasci iz Vinče, Starinar, n.r.g. I, 2 (1906), pp. 89 ff. Prilozi ka reševanju trojanskih problema, Glas Srpske Kraljevske Akamije, LXX (1906), pp. 163 ff. Izveštaj o stanju i radu u Narodnom Muzeju u god. 1907., Godišnjak S. K. A., XXI (1907), pp. 250 ff. Southeastern elements in the pre-historic civilization of Servia, Annual of the British School at Athens, XIV (1907–1908), pp. 318 ff. Narodni Muzej u 1908. god., Godišnjak S. K. A., XXII (1908), pp. 147 ff. Das prähistorische Fundort Vinča in Serbien, Memnon, I, 2 (1907), pp. 177 ff. Narodni Muzej u 1909. god., Godišnjak S. K. A., XXIII (1909), pp. 160 ff. Narodni Muzej u 1910. god., Godišnjak S. K. A., XXIV (1910), pp. 258 ff. Žuto Brdo, Starinar, n.r.g. V (1910), pp. 1 ff. Die Hauptergebnisse der prahistorischen Ausgrabung in Vinča im Jahre 1908, Prähistorische Zeitschrift, II, 1 (1910), pp. 23 ff. Narodni Muzej u 1911. god., Godišnjak S. K. A., XXV (1911), pp. 246 ff. Die Datierung der Vinčaschicht, Prah. Zeit., III, 1–2 (1911), pp. 126 ff. Gradac.

Preistorijsko nalazište latenskoga doba, Glas S. K. A., LXXXVI (1911), pp. 97 ff. Narodni Muzej u 1912. god., Godišnjak S. K. A., XXVI (1912), pp. 180 ff. Narodni Muzej u 1913. god., Godišnjak S. K. A, XXVII (1913), pp. 263 ff. Excavations on the Neolithic site at Vinča, on the Danube, 1930, Man, XXX (1930), pp. 197 ff. Preistorijska Vinča I. Industrija cinabarita i kosmetika u Vinči (Beograd, 1932). Die Organisation der prahistorischen Forschung im unteren Donautale, Proceedings of the First International Congress of Prehistoric and Protohistoric Sciences; London, August 1–6, 1932 (1934), pp. 206 ff. Colons grecs à Vinča, Revue Internationale des Etudes Balkaniques, I (Beograd, 1934), pp. 65 ff.

ŽUJEVIĆ, J. V., AND VALTROVIĆ, M., Staro selište u Barajevu, Starinar, VIII, 1–2 (1891), pp. 1 ff.

FURTHER OBSERVATIONS ON THE PECTORAL GIRDLE AND FIN OF SAURIPTERUS TAYLORI HALL, A CROSSOPTERYGIAN FISH FROM THE UPPER DEVONIAN OF PENNSYLVANIA, WITH SPECIAL REFERENCE TO THE ORIGIN OF THE PENTADACTYLATE EXTREMITIES OF TETRAPODA

WILLIAM K. GREGORY

HISTORICAL INTRODUCTION

The type specimen of *Sauripterus taylori* Hall, which is preserved in the Geological Department of the American Museum of Natural History, is one of the two most important extant palæontological documents bearing on the origin of the cheiropterygium, the other being the pectoral girdle and limb of *Eusthenopteron foordi* Whiteaves, represented in various specimens described by Whiteaves, A. S. Woodward, Hussakof, Goodrich, Bryant, Petronievics. James Hall (1843), the describer of *Sauripterus taylori*, had the knowledge and insight to apply the words "clavicle," "rudimentary humerus, ulna, radius and phalanges" to different parts of the type and only known specimen, which is preserved in a block of reddish brown sandstone from the vicinity of Blossburg, Pennsylvania, dating from Chemung (Upper Devonian) times. Hall also invented the name *Sauripterus* to express the apparent intermingling of fish and saurian characteristics which are to be observed in the pectoral girdle and fin. But his excellent figures of these parts seem to have remained long unnoticed even by those who afterward debated the subject of the origins of the paired fins and the cheiropterygium. In 1891, however, A. Smith Woodward after a personal study of the specimen referred it to the crossopterygian family Rhizodontidæ.

It was not until 1908 that Hussakof published a photograph of the type of *Sauripterus taylori* and made a drawing

of it which was used in 1912 by Bertram G. Smith in his work
on the embryology of *Cryptobranchus*, in connection with his
brief remarks on the probable origin of the Amphibia from
crossopterygians. Meanwhile the writer (1911), after having
studied the type of *Sauripterus taylori*, attempted, not alto-
gether successfully as it now appears, to establish homologies
between the several parts of the pectoral girdle and limbs of
Sauripterus, representing the crossopterygians, and *Eryops*,
representing the earlier stegocephalian Amphibia. In 1913
Broom gave a sketch-restoration of the pectoral girdle of
Sauripterus and conjectured that in the passage from the
crossopterygian to the primitive amphibian condition only
the distal rods beyond the enlarged preaxial bone or "radius,"
which he supposed might have been of assistance in crawling
and digging, persisted and gave rise to the digits of amphi-
bians, while all those rods which were supported by the re-
maining or ulnar side retained the functions of a paddle until
the need for them ceased, after which they disappeared en-
tirely, so that they are not represented in the tetrapod limb.

In 1915 I published a paper entitled "Present Status
of the Problem of the Origin of the Tetrapoda, with Special
Reference to the Skull and Paired Limbs," in which the
pectoral girdle and fin of *Sauripterus taylori* were illustrated
by a large and carefully executed sepia drawing by L. A.
Adams. In this paper it was held that since in the earliest
Amphibia all the digits converged toward the ulnar and
fibular side of the limbs, it was only the corresponding rays
in *Sauripterus* that gave rise to the five-rayed limbs of primi-
tive tetrapods, a conclusion which is again supported in the
present paper.

Meanwhile Patten (1912) had used the *Eusthenopteron*
fin as his starting-point for the cheiropterygium, while D. M.
S. Watson in a brief paper in 1913 held that the fourth digit
of tetrapods together with the ulnare, the ulna and the hum-
erus represented the jointed axis of the fin of *Eusthenopteron*.
Among subsequent papers dealing especially with the problem
of the origin of the cheiropterygium may be noted those of

Schmalhausen (1915, 1917), Petronievics (1918), Gregory, Miner and Noble (1923), Broom (1930, p. 106), Gregory (1928, 1934), Romer and Byrne (1931) and Howell (1935).

The derivation of the skull patterns of the oldest tetrapods from a primitive crossopterygian type has in recent years been practically demonstrated, especially in the memoirs of D. M. S. Watson and Säve Söderbergh. Moreover, Watson (1926) has described the pectoral girdle of *Eogyrinus*, one of the British Lower Carboniferous embolomeres, which is almost intermediate between the crossopterygian and the typical embolomerous condition. Recently the Upper Devonian footprints described by Willard (1935) as *Paramphibius tridactylus* and *P. didactylus* have raised new hope that the problem of the origin of the cheiropterygium may be solved even in details. There is therefore strong reason for believing that at one time the true intermediates between the pattern of the pectoral paddle of a generalized crossopterygian type and those of the earliest embolomerous amphibians did exist and in the meantime the pectoral paddles of *Sauripterus* and *Eusthenopteron* are the nearest approach to such a generalized type yet known.

SAURIPTERUS

During the present investigation the type of *Sauripterus taylori*, together with available material of *Eusthenopteron*, *Ectosteorhachis* (= *Parabatrachus*), *Osteolepis*, etc., was again subjected to a most prolonged and intensive scrutiny. I had also at hand a small but very useful series of sketches of parts of the pectoral girdles of *Rhizodus* and other British crossopterygians which I had made in 1913 in the Royal Scottish Museum, Edinburgh, and in the British Museum (Natural History), London. Nor did I neglect to glean every bit of information on crossopterygian girdles and paddles that I could get from the text or illustrations in the literature, especially from Hussakof, Bryant and earlier authors on *Eusthenopteron*, from Traquair on *Tristichopterus*, Wellburn and Watson on *Megalichthys*, and others.

On the stegocephalian side I again had recourse to the

Fig. 1.   The original specimen of *Sauripterus taylori* Hall.   One-third natural size.
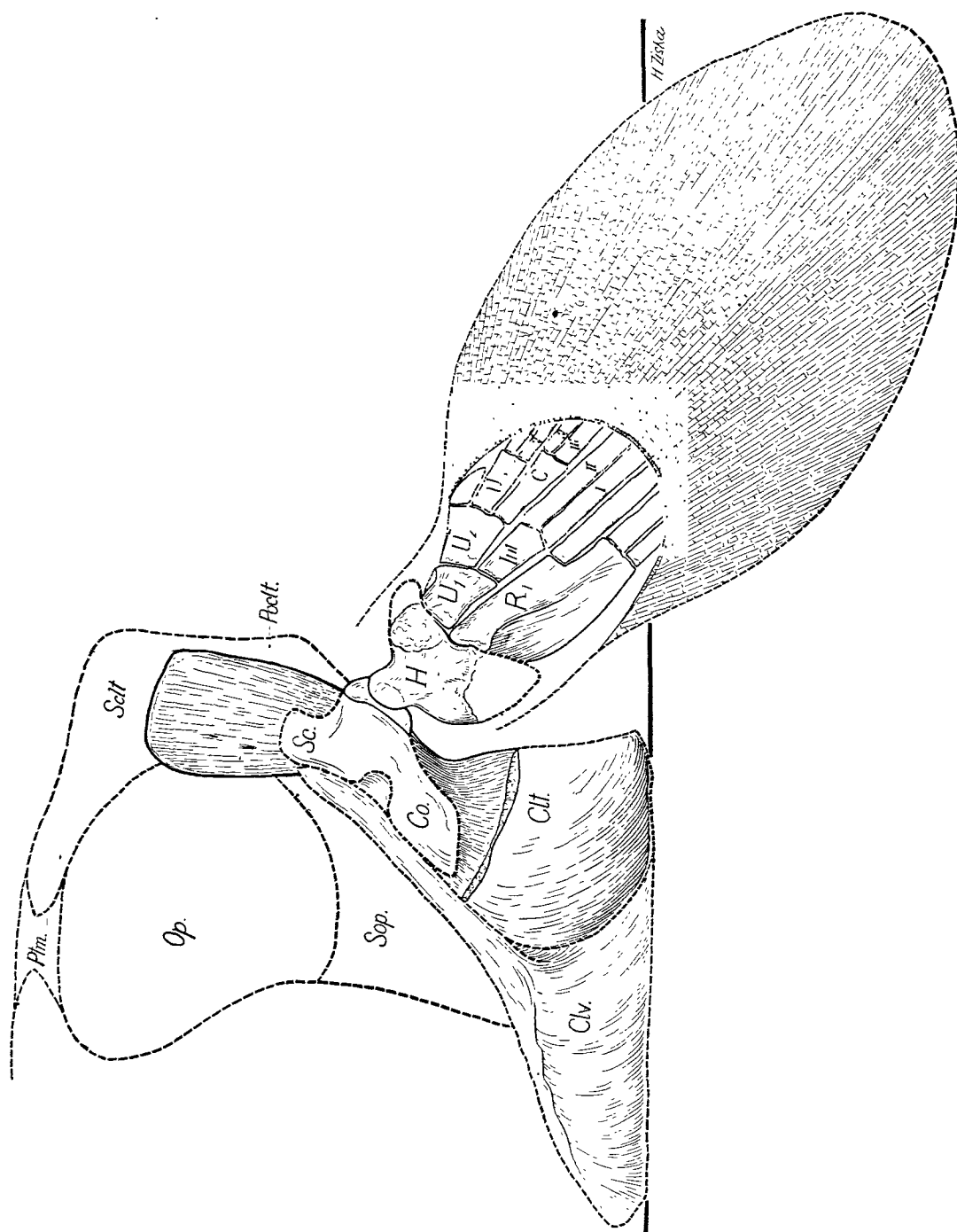
FIG. 2.   Restoration of pectoral girdle and paddle of *Sauripterus taylori*.   Medial view of right side.   One-third natural size.

remarkably well preserved fore foot of Cope's *Eryops megacephalus*.

In Fig. 1 we have tried to represent the pectoral girdle and paddle of *Sauripterus taylori* exactly as it is preserved today, even with its imperfections and without any interpretations. In the restoration (Fig. 2), on the other hand, we have embodied the results of all our investigations on the pectoral region of this and allied genera of crossopterygians.

In *Sauripterus* the parts preserved, in addition to the pectoral paddle, are the cleithrum, parts of the supracleithrum and postcleithrum (?), and a section of the glenoid fossa of the scapulo-coracoid. Several large scales or scaly plates appear on the anteroventral margin of the "radius," while about seven dermal rays adhere in a cluster to the distal lobate region of the paddle. Other fragments near by, apart from the posterior part of the mandible, are of doubtful significance. A series of vertebræ found on another slab of sandstone and figured by Hussakof (1908) recall those of *Eusthenopteron*. In the cleithrum the lower spatulate expansion, which turned inward at a sharp angle to the blade, lacks the greater part of the ventral ramus. It bears on its antero-internal margin an obliquely placed, narrow and flattened strip against which the ascending process of the clavicle was probably appressed. The latter was not found but in our tentative restoration we have given it a form much like that of *Rhizodus* as figured by A. S. Woodward (1891, pl. XII). The missing portions of the scapulo-coracoid probably extended above the glenoid to afford support against the upward oblique thrusts of the pectoral paddle; from the glenoid fossa the coracoid must have extended downward and forward beneath the ascending ramus of the true clavicle. As restored it is essentially similar to the coraco-scapula of *Eusthenopteron* (Bryant) and *Megalichthys* (Watson, 1926, p. 252). The glenoid fossa was deeply concave and evidently permitted rotary movements of the humerus, which has a globose head. From the position of the glenoid it is plain that the normal direction of the pectoral paddle was backward and partly downward.

The pectoral paddle of *Sauripterus*, like that of *Tristichopterus* and *Eusthenopteron*, included first, an axial series of "basals" (Traquair) or axonosts (Petronievics) and second, a more or less parallel series of "radials" (Traquair), which articulate with one side of the axis. The first of the radials in *Sauripterus* is a very large plate of bone without visible trace of subdivision on the lower border of the fin. It is evidently homologous with the first radial of *Eusthenopteron* and *Tristichopterus* and it has been homologized by all authors except Romer with the radius of amphibians.

In the great size of the "radius" *Sauripterus* surpasses *Megalichthys* and related genera. This seems to imply some special habit such as scooping the mud with the large scales or plates on the anterior surface of the radius, possibly in connection with nest-making habits. That the pectoral paddle was equipped with strong fan-like superficial and deep muscles for spreading, contracting and vibrating the rods of the fin as well as for twisting and turning the paddle and for bending it, is implied by the size and strength of the elevations on the inner surface of the cleithrum, by the presence of stout processes on the humerus and on certain of the axial or "basal" pieces, as well as by the roughened depressed areas on the humerus.

Another conspicuous feature of the pectoral paddle of *Sauripterus* is the strong development of the most distal digital rods, near the peripheral border of the lobate or muscular part of the paddle. With one exception these rods do not appear to have been ossified in *Eusthenopteron* as indicated by Bryant's and our own material. The exception noted is a small rod near the distal end of the jointed or basal series present in one of Bryant's specimens. In the type specimen of *S. taylori* as preserved the jointed series of "basal" rods, or axonosts, is found on or near the dorsal border of the paddle, while the broad first radial is found on the lower border. But since the humerus rotated on a ball-and-socket joint in the glenoid articulation, one might wonder whether the *Sauripterus* paddle could not have been twisted upside
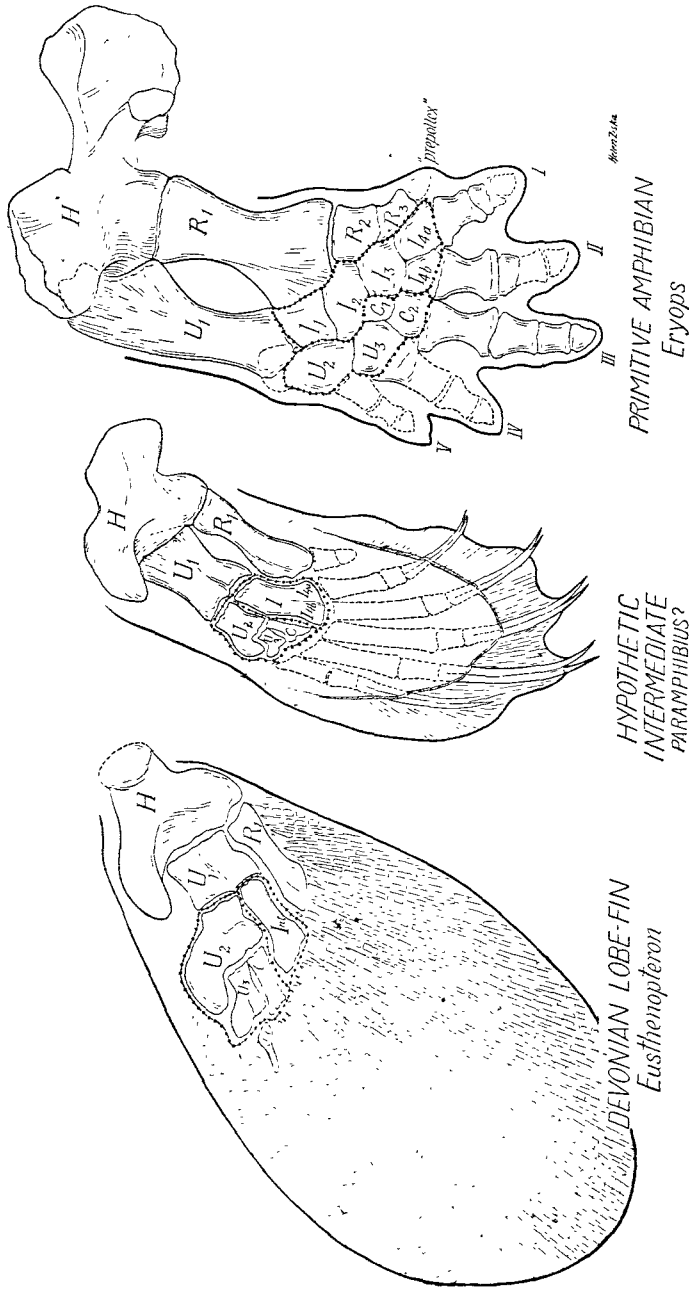
FIG. 3. Transformation of crossopterygian paddle into pentadactylate limb. Author's theory. Medial view of left side.

A. *Eusthenopteron foordi.* Based on material of Bryant and author.
B. *Hypothetic intermediate.*
C. *Eryops megacephalus.* Based on Cope's material in the American Museum of Natural History.
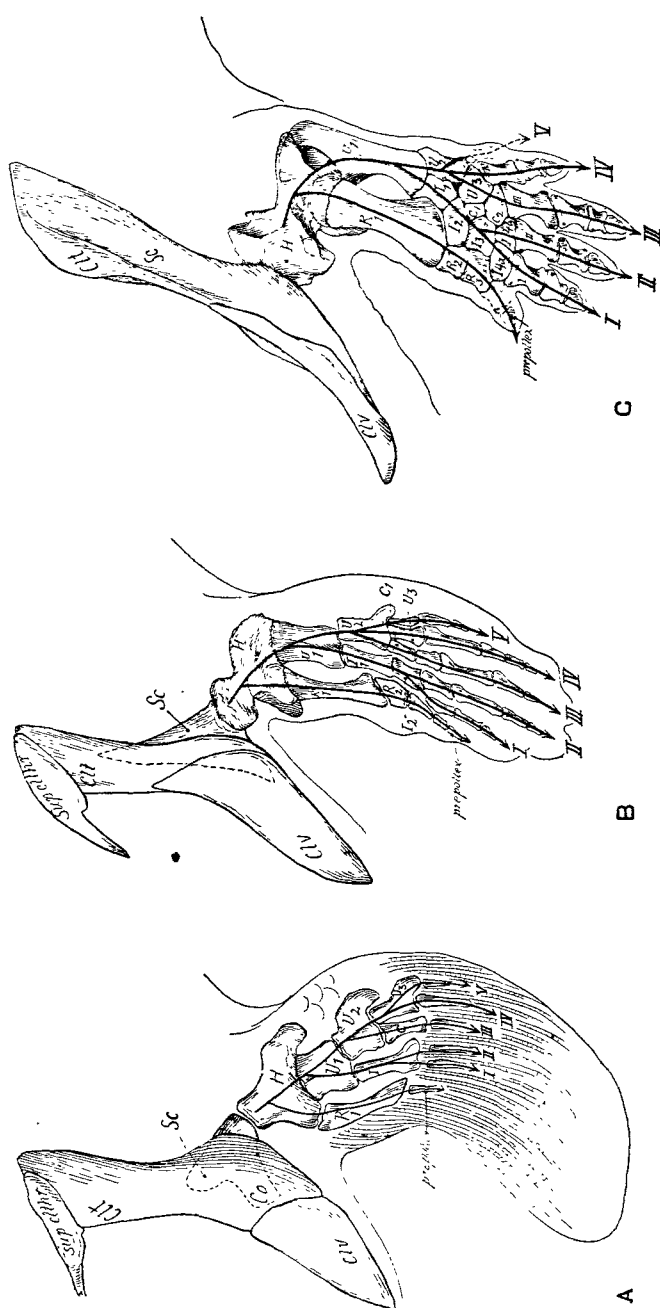
FIG. 4. Transformation of crossopterygian pectoral girdle and paddle into pentadactylate type. Author's theory. Oblique front view of left side.

A. *Eusthenopteron foordi.* Based on material of Bryant and author.
B. Partly hypothetic intermediate. Girdle supplied from Watson's *Eogyrinus.*
C. *Eryops megacephalus.* Based on Cope's material in the American Museum.

down.   That this is not so is indicated by several considera-
tions: (1) In the beautifully preserved Albany Museum speci-
men of *Eusthenopteron* described by Hussakof (1912) the left
pectoral fin is found in exactly the same position as that of
Sauripterus, with the jointed basal series on the upper border;
(2) the same is true in Bryant's *Eusthenopteron;* (3) if the
jointed basal rods were placed along the ventral border the
strong movable radials of the fin would point forward and
upward and the more freely vibrating border of the fin would
tend to draw the head downward and backward, whereas in
the living *Polypterus*, which has the most nearly similar fin
among modern fishes, the pectorals when directed partly
downward tend to drive the head forward and upward; (4)
in the skeleton of many aquatic types of vertebrates the more
convex and stiffer line of bony elements lies on or nearer to
the anterior border of the appendage, while the more freely
movable borders are directed to the rear (e.g., ichthyosaurs,
plesiosaurs, marine chelonians, etc.).

The Origin of the Cheiropterygium

In comparing the elements of the pectoral paddle of
Sauripterus with those of amphibians, the large bone on the
lower border of the paddle immediately behind the "hum-
erus" has commonly been homologized with the radius,
while the first small bone above it has been called "ulna."
This interpretation has, however, recently been challenged
by Romer (in Romer and Byrne, 1931) chiefly on the ground
of his studies on the development of the muscles of the girdle
and limbs in the lower vertebrates.   According to Romer's
hypothesis, the lateral surface of the crossopterygian paddle
by bending at the elbow and twisting forward and inward
gave rise to the palmar surface of the cheiropterygium, while
the dorsal ray of the paddle became the pollex of the cheirop-
terygium.   This would make the large anteroinferior bone of
the paddle homologous with the ulna and the small bone above
it homologous with the radius (cf. Fig. 5).   Several years
ago in order to test this hypothesis by experiments I super-

vised the preparation by Mrs. Helen Ziska of a series of drawings of the pectoral limb of a generalized crossopterygian (essentially *Eusthenopteron* but with additions from *Sauripterus*). The drawings were then projected upon both sides of some thin flexible drawing paper. By bending and twisting these models we were able to put the limb into successive positions, first according to the current hypothesis that the radius is represented by the lower of the two bones beyond the humerus (Fig. 4) and next (Fig. 5) according to Romer's hypothesis, to the consideration of which I shall return below.

Passing now to the consideration of the probable condition of the pectoral and pelvic fins in the lost interval between the crossopterygians and the oldest known amphibians, we may examine first the medial surface of the pectoral limb of *Eryops megacephalus* Cope, in which the entire carpus and most of the digits are preserved nearly in the natural positions. An extremely significant and important fact is that in this pectoral limb as well as in the pelvic limb of *Trematops* as figured by Williston (1909) all the carpals except the radial series are arranged in an obliquely placed system which extends upward and backward to the ulna, whereas in numerous restorations of the supposedly primitive pattern of the tetrapod manus, the carpal bones have been placed in transverse rows, as they are indeed in most later tetrapods. This oblique arrangement is distinctly noted in my 1915 diagram of the pectoral and pelvic limbs of primitive amphibians and it is very clearly shown in the carpus of foetal urodeles as figured by Schmalhausen (1915). Moreover, in *Eryops* the radius extends far below the level of the lower end of the ulna and the radial carpals form a distinct series which bends away from the shaft and seems to occupy the position of the "prepollex" of recent amphibians. Brazier Howell (1935) limits the "prepollex" to the prepollicial carpal. According to the hypothesis here advanced, however, the radius in the crossopterygian stage carried several rods which eventually disappeared except for possible traces in the prepollicial carpals, while the future digits I–V all converged toward the ulna.

Now as already noted, there is very good evidence from skull patterns, teeth and vertebræ that the early stegocephalians including *Eryops* were derived eventually from the stem of the crossopterygian fishes. Hence it is likewise probable that the limbs of *Eryops* have been derived from crossopterygian paddles that were essentially similar to those of *Eusthenopteron* and *Sauripterus*. The humerus of *Eryops* corresponds perfectly in position with the humerus of the crossopterygians. In the latter the so-called radial element corresponds in position with the radius and "prepollex" of amphibians. The other radials incline toward the "ulna" much as the carpals of *Eryops* incline toward its ulna. But how are we to derive the individual carpal bones of amphibians from the "radials" of crossopterygians and whence came the digits of amphibians?

After many futile attempts to answer these problems, I at last hit upon the solution which is embodied in Figs. 3, 4. This theory assumes that the digits and metacarpals of amphibians are derived by the breaking up and rearrangement of the elements of a *Sauripterus*-like pectoral paddle, as follows:

(1) *radial rods* to the carpal elements of the "prepollex";

(2) *Intermedial rods* to the intermedium, mediale and carpalia 1, 2;

(3) *central rods* to the centrale and carpale 3;

(4) *ulnar rods* to ulnare and carpalia 4, 5;

(5) *distal radial rods* to metacarpals and phalanges;

(6) *dermal rays* to nails.

Figs. 3, 4 illustrate the hypothesis that as the paddle was progressively turned downward and forward a sharp bend developed at the future shoulder, elbow and wrist, the future ulna lengthened and the carpals, bending upon the ulna, were stopped by the lower end of the future radius. Then in embryonic stages there was a marked segmentation of the distal rods, producing the metacarpals and phalanges, and a less marked segmentation of the carpals, so that the "intermedial" rod gave rise to the intermedium and the elements

distal to it, including carpalia 2, 3, while the "central" rod
divided into one centrale and carpale 3; the ulnar rod sub-
divided into the ulnare and carpalia 4, 5. Meanwhile the
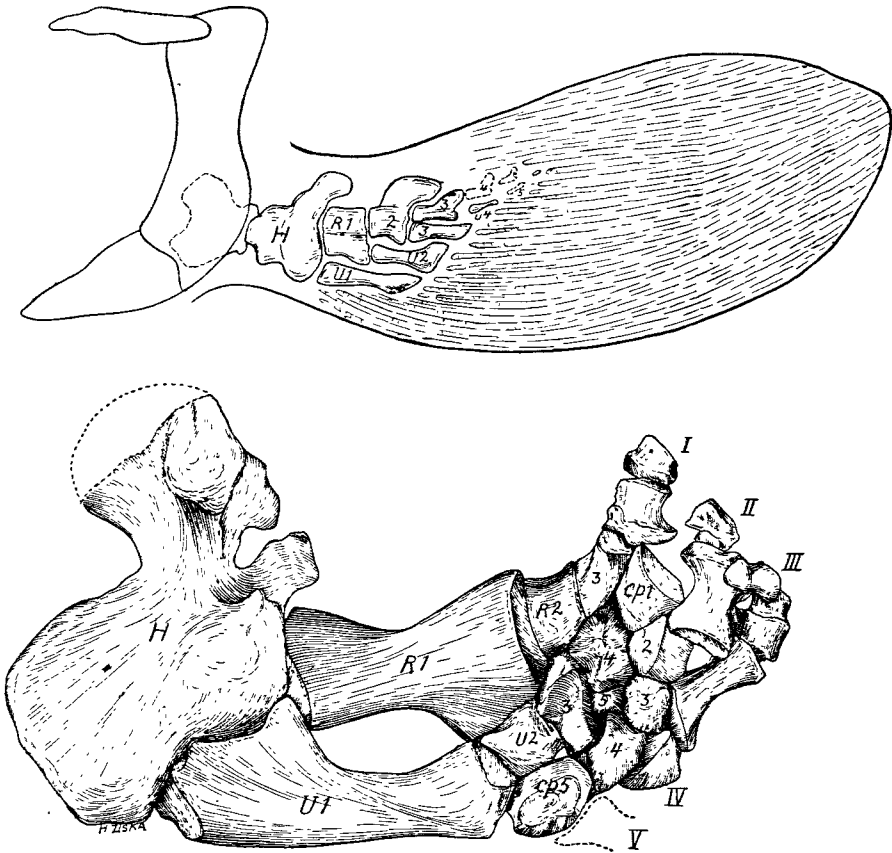
FIG. 5. Comparison of pectoral girdle and limb of crossopterygian and *Eryops*,
showing homologies of parts according to Romer's theory.

jointed series of basals on the radial side gave rise to the
radiale, mediale and the "prepollex."

Romer's hypothesis that the lateral surface of the cros-
sopterygian fin became the palmar surface of the amphibian
hand is applied in Figs. 5, 6. One way in which the trans-
formation according to Romer's hypothesis might have taken
place is indicated in Fig. 7. Here we see that if R 1 were
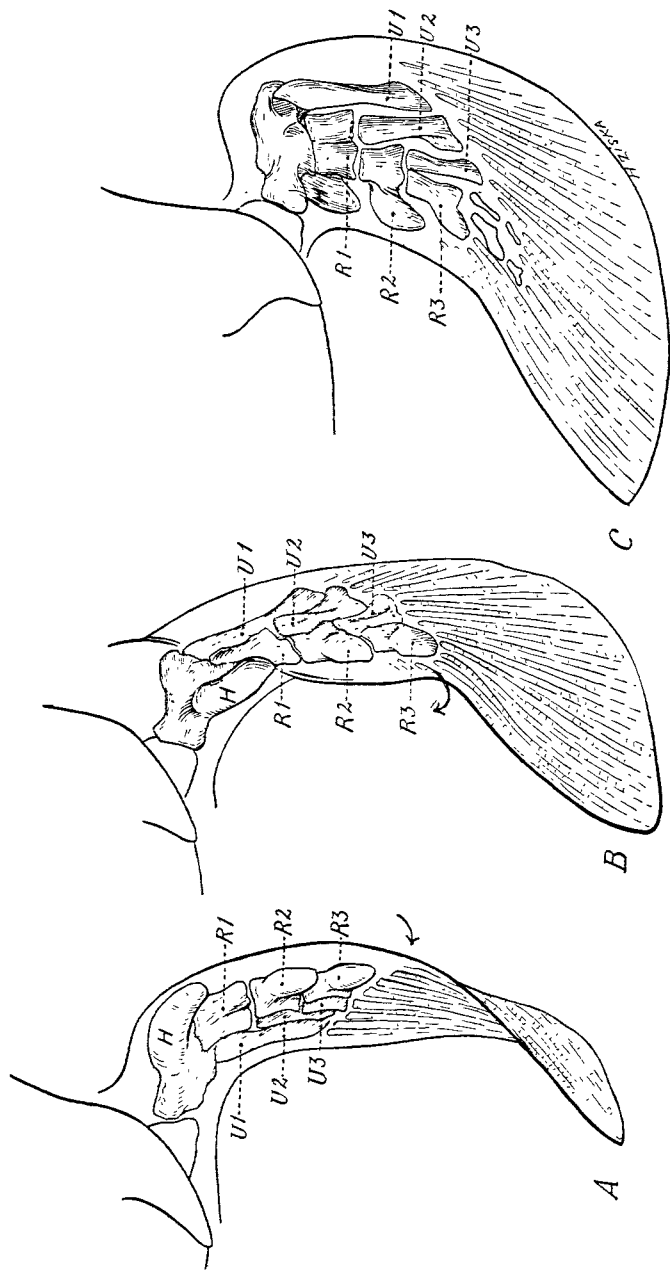
Fig. 6. Turning over and twisting of crossopterygian paddle; homologies according to Romer.

greatly lengthened, R 2, 3, 4, etc. would be pushed distally. If at the same time U 2, 3, 4, 5 were thrust proximally, they might be crowded into the space indicated between the heavy
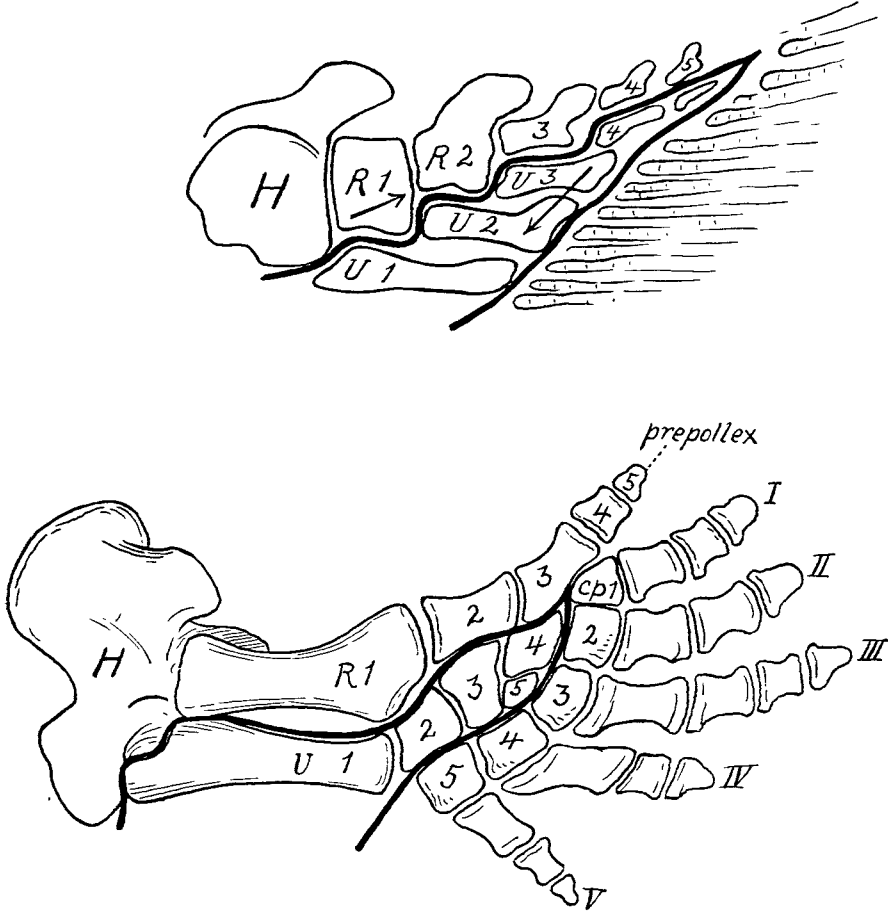
Fig. 7. Possible derivation of amphibian conditions by anisomerous or differential shortening and lengthening of certain parts, conceived according to the homologies postulated by Romer.

black lines in the diagram. But we have no direct evidence that such contrary overthrusts did occur. Moreover, this particular development of Romer's hypothesis would leave the carpalia unaccounted for unless they represent separated

proximal ends of the metacarpal rods. On the whole the hypothesis embodied in Figs. 3, 4 requires less to be taken for granted and makes the various parts of the paddle much easier to homologize with particular parts of the amphibian limb.

LITERATURE CITED

BRAUS, H. 1901. Die Muskeln und Nerven der Ceratodusflosse: Ein Beitrag zur vergleichenden Morphologie der freien Gliedmaasse bei niederen Fischen und zur Archipterygiumtheorie. *Denkschr. d. Med.-Nat. Gesell. Jena*, IV, pp. 137–300, pls. 21–29, 25 figs.

BROOM, ROBERT. 1913a. On the Structure of the Mandible in the Stegocephalia. *Anat. Anz.*, XLV, No. 2/3, pp. 73–78, 4 figs.

1913b. On the Origin of the Cheiropterygium. *Bull. Amer. Mus. Nat. Hist.*, XXXII, Art. 27, pp. 459–464, 6 figs.

1930. The Origin of the Human Skeleton: An Introduction to Human Osteology. London. H. F. and G. Witherby. [*Sauripterus*, pp. 106–109; figs. 36, 37.]

BRYANT, W. L. 1919. On the Structure of *Eusthenopteron*. *Bull. Buffalo Soc. Nat. Sci.*, XIII, No. 1, 23 pp., 18 pls.

COPE, E. D. 1880. Second Contribution to the History of the Vertebrata of the Permian Formation of Texas. *Proc. Amer. Philos. Soc.*, XIX, pp. 38–58, 4 pls. [*Eryops megacephalus*, pls. 1–4.]

DEAN, BASHFORD. 1906. Notes on the Living Specimens of the Australian Lungfish, *Ceratodus forsteri*, in the Zoological Society's Collection. *Proc. Zool. Soc. Lond.*, 1906, January-April, I, pp. 168–178, pl. 9. [Postures and movements of paired fins.]

1909. Studies on Fossil Fishes (Sharks, Chimæroids, and Arthrodires). *Mem. Amer. Mus. Nat. Hist.*, IX, Part 5, pp. 211–287, pls. 26–41. [*Cladoselache* and origin of paired fins.]

GOODRICH, E. S. 1909. Vertebrata Craniata (First Fascicle: Cyclostomes and Fishes). In "A Treatise on Zoology." Ed., Sir Ray Lankester. Part IX. London. [*Eusthenopteron*, fig. 258.]

1928. *Polypterus* a Palæoniscid? *Palæobiologica*, I, pp. 87–92.

GREGORY, WILLIAM K. 1911. The Limbs of *Eryops* and the Origin of Paired Limbs from Fins. *Science*, N. S., XXXIII, pp. 508–509.

1913a. Crossopterygian Ancestry of the Amphibia. *Science*, N. S., XXXVII, No. 960, pp. 806–808, May 23, 1913.

1913b. Locomotive Adaptations in Fishes illustrating "Habitus" and "Heritage." *Ann. N. Y. Acad. Sci.*, 10 Feb., 1913, pp. 266–268.

1915. Present Status of the Problem of the Origin of the Tetrapoda with special reference to the Skull and Paired Limbs. *Ann. N. Y. Acad. Sci.*, XXVI, pp. 317–383, pl. 4, 15 figs.

1923. (With R. W. Miner and G. K. Noble.) The Carpus of *Eryops* and the Structure of the Primitive Chiropterygium. *Bull. Amer. Mus. Nat. Hist.*, XLVIII, Art. 10, pp. 279–288, 4 figs.

1928. The Upright Posture of Man: A Review of Its Origin and Evolution. *Proc. Amer. Philos. Soc.*, LXVII, No. 4, 339–376, 2 pls., 15 figs. [Origin of chiropterygium, Fig. 6.]

1930. Basic Patents in Evolution. Part I. *Scientific American*, August, 1930, pp. 112–113, figs. 1–5; Part II. *Idem*, Sept., 1930, pp. 200–202, figs. 6–12; Part III. *Idem*, Oct. 1930, pp. 286–288, figs. 13–18. [Pectoral girdle and paddle, figs. 7–12.]

1933. Basic Patents in Nature. Address of the president of the N. Y. Acad. Sci., Dec. 18, 1933. *Science*, 78, No. 2034, pp. 561–566.

HALL, JAMES. 1843. Geology of New York. Part IV. Comprising the Survey of the Fourth Geological District. In "The Natural History of New York." Published by Authority. New York, Boston, Albany. [*Sauripterus*, pp. 281, 282, pl. 3, figs. 1–3.]

HOWELL, A. BRAZIER. 1933a. Morphogenesis of the Shoulder Architecture. Part I. General Considerations. *Quart. Rev. Biol.*, VIII, No. 3, pp. 247–259, 4 figs.

1933b. Morphogenesis of the Shoulder Architecture. Part II. Pisces. *Quart. Rev. Biol.*, VIII, No. 4, pp. 434–456, 13 figs.

1935. The Primitive Carpus. *Journ. Morph.*, LVII, No. 1, pp. 105–112. [*Sauripterus*, Fig. 1.]

HUSSAKOF, L. 1908. Catalogue of the Type and Figured Specimens of Fossil Vertebrates in the American Museum of Natural History. Part I.—Fishes. *Bull. Amer. Mus. Nat. Hist.*, XXV, pp. 1–103, 6 pls., 49 figs. [Type of *Sauripterus taylori*, figs. 27, 28.]

1912. Notes on Devonic Fishes from Scaumenac Bay, Quebec. *N. Y. State Mus. Bull.*, CLVIII, Eighth Rept., pp. 127–139, 3 pls., 6 figs. [*Eusthenopteron*, p. 131, fig. 2.]

1918. Catalog of the Fossil Fishes in the Museum of the Buffalo Society of Natural Sciences. *Bull. Buffalo Soc. Nat. Sci.*, XII, pp. 1–346, 70 pls., 64 figs., [*Eusthenopteron*, pp. 176–178, pl. 70, fig. 2.]

KLAATSCH, H. 1896. Die Brustflosse der Crossopterygier. *Festschr. f. C. Gegenbaur*, Leipzig, 1896, I, pp. 261–391, 4 pls. [*Polypterus*, musculature of pectoral limb pls. 2, 3.]

MINER, R. W. 1925. The Pectoral Limb of *Eryops* and Other Primitive Tetrapods. *Bull. Amer. Mus. Nat. Hist.*, LI, Art. 7, pp. 145–312, 104 figs.

PETRONIEVICS, BRANISLAV. 1918. Note on the Pectoral Fin of *Eusthenopteron*. *Ann. Mag. Nat. Hist.*, Ser. 9, II, pp. 471–476, 2 figs.

REGAN, C. TATE. 1904. The Phylogeny of the Teleostomi. *Ann. Mag. Nat. Hist.*, Ser. 7, XIII, pp. 329–349, pl. 7, 4 figs. [Evolution of median and paired fins, fig. 2.]

ROMER, A. S. AND BYRNE, F. 1931. The Pes of *Diadectes*: Notes on the Primitive Limb. *Palæobiologica*, IV, pp. 24–48, 9 figs.

SÄVE-SÖDERBERGH, G. 1932. Preliminary Note on Devonian Stegocephalians from East Greenland. *Meddelelser om Gronland*, XCIV, No. 7, 107 pp., 22 pls, 22 figs. [Skulls of "Ichthyostegalia."]

SCHMALHAUSEN, J. J. 1915. The Development of the Extremities in Amphibians and Their Significance in the Question of the Origin of the Extremities of Terrestrial Vertebrates. Moscou. 263 pp., 10 pls., 18 figs.

1917. On the Extremities of *Ranidens sibiricus* Kessl. *Revue Zool. Russe*, II Part 5, pp. 129–138, 5 figs.

Undated. Fundamentals of the Comparative Anatomy of Vertebrates. Government Publ., Moscou and Petersburg. 425 pp., 266 figs.

SMITH, BERTRAM G. 1912. The Embryology of *Cryptobranchus allegheniensis*, including comparisons with some other Vertebrates. II. General Embryonic and Larval Development, with special reference to external features. *Journ. Morphol.*, XXIII, No. 3, pp. 455–562, pls. 3–10, figs. 57–203. [Phylogeny of the Amphibia, pp. 540–557; pectoral fin of *Sauripterus*, fig. 203.]

TRAQUAIR, R. H. 1876. On the Structure and Affinities of *Tristichopterus alatus*, Egerton. *Trans. Roy. Soc. Edinburgh*, XXVII, Part 18, pp. 383–396, pl. 32.

WATSON, D. M. S. 1913. On the Primitive Tetrapod Limb. *Anat. Anz.*, XLIV, No. 1/2, pp. 24–27, 1 fig.

1926. Croonian Lecture: The Evolution and Origin of the Amphibia. *Philos. Trans. Roy. Soc. London*, Ser. B, CCXIV, pp. 189–257. [*Eogyrinus*, figs. 18–25; *Eusthenopteron*, figs. 34, 35; *Megalichthys*, figs. 32, 33, 36–39.]

WELLBURN, EDGAR D. 1902. On the Genus *Megalichthys*, Agassiz: Its History, Systematic Position, and Structure. *Proc. Yorkshire Geol. Polytech. Soc.*, N.S., XIV, 1900–1902, pp. 52–71, pls. 13–19.

WHITEAVES, J. F. 1889. Illustrations of the Fossil Fishes of the Devonian Rocks of Canada. Part II. *Trans. Roy. Soc. Canada*, 1888 (1889), VI, Sec. 4, pp. 77–96, pls. 5–10. [*Eusthenopteron*, pls. 6, 7, 10.]

WILLARD, BRADFORD. 1935. Chemung Tracks and Trails from Pennsylvania. *Journ. Paleont.*, IX, No. 1, pp. 43–56, pls. 10, 11. [*Paramphibius*, pls. 10, 11; origin of Amphibia, p. 52.]

WILLISTON, S. W. 1909. New or Little-known Permian Vertebrates: *Trematops*, New Genus. *Journ. Geol.*, XVII, No. 7, pp. 636–658, 7 figs. [Pelvic limb, fig. 5.]

WOODWARD, A. S. 1891. Catalogue of the Fossil Fishes in the British Museum (Natural History). Part II. Containing the Elasmobranchii (Acanthodii), Holocephali, Ichthyodorulites, Ostracodermi, Dipnoi and Teleostomi (Crossopterygii and Chondrostean Actinopterygii). London. Printed by Order of the Trustees of the British Museum. [*Rhizodus*, pl. 12; *Sauripterus*, pl. 16.]

1898. Outlines of Vertebrate Palæontology for Students of Zoology. Cambridge Univ. Press. 470 pp., 228 figs. [*Pleuracanthus*, fig. 17, 18, 22; *Eusthenopteron*, figs. 23, 58.]

1906. The Study of Fossil Fishes. Presidential Address. *Proc. Geol. Assoc. London*, XIX, pp. 266–282, 15 figs. [Restoration of skeleton of *Cheirolepis*.]

THE PEDICELLATE PEPPERS OF SOUTH AMERICA

WILLIAM TRELEASE

THE Piperaceae are generally characterized by having their small naked flowers sessile and in what are called technically spikes or more properly aments or catkins, though they were referred to frequently by earlier writers as spadices.

The first American exception to this type of inflorescence was collected by Ryan in the island of Trinidad and sent to Martin Vahl of Copenhagen, who described and figured it in 1796 under the name *Piper ovatum*.

Early in the nineteenth century a second species was collected on Mount Corcorvado and elsewhere in the near vicinity of Rio de Janeiro by Gaudichaud and Guillemin, and because of its racemose inflorescence and its tetramerous flowers this was made the basis of a distinct genus in 1820, and named *Ottonia anisum* by Sprengl. Shortly afterwards this Brazilian plant was differentiated independently by its discoverers who described and illustrated it admirably under the binomial *Serronia Jaborandi*. Evidently, the French and German botanists who so christened the plant on one set of collections worked in ignorance of each other's activities but their publications, though prepared at nearly the same date, appeared over a decade and a half apart.

In 1839, not long after *Serronia* was published, Kunth took up the generic name *Ottonia* for these species and a number of others with pedicellate flowers, as well as a few that closely resemble them in foliage and 4-merous flowers, though these are sessile.

Subsequent collectors have added considerably to even the species of *Ottonia* recognized by Kunth; but although his genus was accepted by Miquel, who monographed the Piperaceae in the middle of the next decade, it was held to be more properly a subdivision of *Piper* than an adequately

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distinguishable genus by Casimir de Candolle in his classic revision of the Piperaceae published a quarter of a century later so that for three-quarters of a century now it has been so treated, largely on his authority.

Under the approved nomenclatorial practice of the last century, specific names were not necessarily retained and were preferably replaced when transfers were made from one genus to another, and this is somewhat confusing when confronted with the now prevalent and reasonable practice of retaining such names when transfers are made. Because of this earlier practice, Kunth abandoned both of Vahl's names when transferring *Piper ovatum* and called it *Ottonia Vahlii*, and Monsieur de Candolle frankly renamed all of Kunth's Ottonias when merging them into Piper, the only specific name that he did not reject in this merger being Jaborandi, a native name adopted by the authors of Serronia.

Though a small genus, *Ottonia* presents the difficulties commonly encountered in differentiating the species of *Piper*, to which must be added the circumstance that in pubescence and leaf-forms its species are even more and more puzzlingly variable.

A second group of racemose peppers, limited to continental North America, which I have segregated under the genus *Arctottonia*, has palmately nerved leaves, while the South American plants constituting *Ottonia* have equally conspicuous pinnate nervation. As thus limited, *Ottonia* is confined, so far as known, to the easternmost part of transequatorial Brazil—overflowing into adjacent Paraguay, with exception of the single widely separated species of Trinidad off the Venezuelan coast.

Though *Ottonia* and *Arctottonia* are the only genera of the family that have stalked flowers, a large number of Peperomias develop a dissemination adjunct by forming a distinct stalk under the flowers after anthesis. Herbarium material, even with spikes from which the fruits have fallen, permit the detection of such "pseudo-pedicels" only now and then, and it remains to be shown with certainty how general their

production is; but two expert and experienced field students of the genus (Henschen, who knew the Peperomias well in Brazil, and Yuncker, who more recently has studied them in Hawaii) have expressed the belief that such pseudopedicellate fruits are characteristic of the genus. Actually, pseudo-pedicels have been figured or definitely reported only for species of the sections *Sphaerocarpidium*, in which many species are known to produce them, and *Micropiper*, in which they are pictured for two species.

Suggestive of the pseudopedicellate and pedicellate flowers, are the Pipers represented by the cubebs of pharmacy, and a number of widely separated species of *Peperomia*, in which the fruits are stalked or stipitate within the flowers.

As in many other monographic studies of extensive and scattered collections, embarrassment has been found here in the fragmentary character of many of the older specimens and in the paucity of data accompanying them—difficulties which may be evaded by ignoring such material but which, if not, must carry implicitly a recognition of its defects.

In the following revision, which takes cognizance of all of the specimens of *Ottonia* that have come under my observa-tion in the great herbaria of the world, descriptions are in English rather than Latin. Those who are familiar with early post-Linnaean publications will recall that the newly devised binomial was commonly followed by an ablative diagnosis corresponding in some sense to the previously used polynomial designation of a species, but the insufficiency of which was tacitly admitted by the addition of a complementary de-scriptive paragraph. The present international agreement on the desirability of a latinized diagnosis of new species is met in the present case by a latinized key to the recognized species, in which their successive differentials constitute an adequate diagnosis—though, as in all cases, evidencing the need of a fuller description.

CLAVIS SPECIERUM

Folia plerumque vix 11 cm. longa, basi obtusa.
  Glaberrimae.
    Pedicelli vix 2 mm. longi.
      Pedicelli perbreves: folia elongata.   *O. brevistipitata.*
      Pedicelli distincte evoluti.
        Folia 4 cm. lata.   *O. colliculorum.*
        Folia 3 cm. lata.   *O. Riedelii.*
    Pedicelli longiores.
      Racemi vix 30 mm. longi   *O. padifolia.*
      Racemi subelongati.
        Folia cordulata.   *O. Clausseni.*
        Folia vix cordulata.   *O. janeiroensis.*
  Aliquanto hirtellae.
    Pedicelli vix 2 mm. longi.
      Racemi 50 mm. longi.   *O. praecox.*
      Racemi 35 mm. longi.   *O. pteropoda.*
    Pedicelli longiores.
      Racemi 30 mm. longi.   *O. carpinifolia.*
      Racemi 60 mm. longi.   *O. Anisum.*
Folia plerumque 10–15 cm. longa.
  Foliorum ratio plerumque vix 2 : 1.
    Pedicelli perbreves; glabrae.   *O. leptostachya.*
    Pedicelli distincte evoluti.
      Glaberrimae.
        Folia basi acuta.
          Folia lanceolato-elliptica.   *O. Novaesii.*
          Folia subrhombica.   *O. Hoehnei.*
        Folia basi obtusa.
          Racemi vix 50 mm. longi.
            Pedicelli vix 2 mm. longi.   *O. Usterii.*
            Pedicelli longiores.   *O. peruibensis.*
          Racemi elongati.
            Pedicelli vix 2 mm. longi.
              Folia haud peltata.
                Pedunculus 5 mm. longus.
                  Folia ovato-elliptica.   *O. Loefgreni.*
                  Folia lanceolato-elliptica.   *O. ituana.*
                Pedunculus 10 mm. longus.   *O. palhosana.*
                Folia aliquot obscure subpeltata.   *O. frutescens.*
      Aliquando hirtellae.
        Folia vix cordulata.   *O. latilimba.*
        Folia obscure cordulata.
          Pedunculus 5 mm. longus.   *O. Martiana.*
          Pedunculus 10 mm. longus.   *O. Mexiae.*
  Folia elongata.
    Glaberrimae.
      Folia basi obtusa.
        Pedicelli vix 2 mm. longi.
          Racemi vix 50 mm. longi.
            Folia basi angustata.
              Folia lanceolata vel elliptica.   *O. subglauca.*
              Folia subrhombea.   *O. Santo-ludoviciana.*

Folia deorsum vix angustata.   *O. Edwallii.*
Racemi elongati.
  Folia basi angustata.
    Folia ovato-lanceolata.   *O. propinqua.*
    Folia oblongo-lanceolata.   *O. corcovadensis.*
  Folia basi vix angustata.
    Folia lanceolata.   *O. atrosanguinea.*
    Folia oblongo-lanceolata.   *O. taperana.*
Pedicelli longiores: folia basi vix angustata.
  Racemi vix 50 mm. longi.
    Racemi sublaxiflori.   *O. Mendoncae.*
    Racemi densiflori.
      Folia subfalcata.   *O. gibbimontis.*
      Folia vix falcata.
        Folia vix cordulata.
          Pedicelli baccae breviores.   *O. Hammari.*
          Pedicelli baccae aequantes.   *O. santa-annae.*
        Folia subcordulata.   *O. elocalis.*
  Racemi elongati.
    Racemi subdensiflori.
      Folia lanceolato-elliptica.   *O. miguelitensis.*
      Folia anguste lanceolata.   *O. lancifolia.*
    Racemi laxiflori.
      Folia deorsum angustata.   *O. machadoensis.*
      Folia basi vix angustata.
        Pedunculus 10 mm. longus.   *O. rio-feioana.*
        Pedunculus brevis.   *O. apodostachya.*
Pedicelli longiores.
  Racemi 30 mm. longi.   *O. santa-ritana.*
  Racemi circa 50 mm. longi.   *O. Glazioui.*
  Racemi 80 mm. longi.   *O. Armondi.*
Folia basi acuta.
  Folia falcata.   *O. Douglasii.*
  Folia vix falcata.   *O. eucalyptifolia.*
Aliquando hirtellae.
  Folia basi acuta vel angustata.
    Folia anguste-lanceolata.
      Ramuli transverse-striati.   *O. striaticaulis.*
      Ramuli vix transverse-striati.
        Racemi 3 × 30 mm.   *O. Hookeriana.*
        Racemi 40–50 mm. longi.   *O. diversifolia.*
    Folia 6 cm. lata.   *O. Schwackeae.*
  Folia basi obtusa: racemi subbreves.
    Pedicelli subelongati.   *O. Burchellii.*
    Pedicelli vix 2 mm. longi.
      Pedunculus 5 mm. longus.   *O. consanguinea.*
      Pedunculus 10 mm. longus.   *O. aguadana.*
Folia plerumque 15 cm. longitudine superantes.
  Folia subelongata.
    Folia basi acuta: racemi et pedicelli longi.   *O. macrostachya.*
    Folia basi obtusa.
      Folia deorsum angustata.   *O. baptisiana.*
      Folia basi vix angustata.

Pedicelli vix 2 mm. longi.
 Racemi vix 70 mm. longi.
  Folia 18–20 cm. longa.   *O. macrophylla.*
  Folia 14–16 cm. longa.   *O. Mosenii.*
 Racemi longi.   *O. albo-punctata.*
 Pedicelli elongati: racemi subbreves. *O. stationis.*
Foliorum ratio plerumque vix 2 : 1.
 Folia vix cordulata.
  Pedicelli elongati.
   Racemi subbreves.   *O. Duseni.*
   Racemi longi.   *O. grandifolia.*
  Pedicelli vix 2 mm. longi.   *O. Muelleri.*
 Folia cordulata. (Extra-brasilienses.)
  Racemi elongati. (Paraguay.)   *O. cordulatifolia.*
  Racemi vix 50 mm. longi. (Trinidad.) *O. ovata.*

SPECIES OF OTTONIA

OTTONIA AGUADANA n. sp.

A nodose shrub 1.5 m. tall, with somewhat hirtellous axes; flowering internodes short; leaves lance-elliptic, somewhat falcately acuminate, obtuse-based, 4.5 × 12–5.5 × 14 cm., pinnately nerved throughout, the nerves some 12 × 2, paler beneath; petiole 5 mm. long; racemes 5 × 45–50 mm.; peduncle scant 5 mm. long; pedicels scarcely longer than the flowers.

Type locality: Fazenda de Aguada, Viçosa, Minas Geraes (Mexia 5178).

Distribution: East-central Brazil.

OTTONIA ALBO-PUNCTATA n. sp.

A glabrous shrub; leaves lance-elliptic, acuminate, subacute-based, 6 × 18 cm., pinnately nerved throughout, the nerves some 10 × 2, pale-punctulate beneath; petiole scant 5 mm. long; racemes 6 × 80–150 mm.; peduncle 5–10 mm. long; pedicels rather longer than the round-ovoid ovaries.

Type locality: Congonhas do Campo, Minas Geraes (Glaziou 15436); Minas (St. Hilaire 28, at Paris).

Distribution: East-central Brazil.

OTTONIA ANISUN Spr., Neu. Entdeck. 1: 255. 1820.

Serronia Jaborandi Gaud. & Guill. in Delessert, Icon. 54. pl. 90. 1837.
Piper Jaborandi Vell., Fl. Flum. pl. 54. 1827.
Ottonia Jaborandi (Vellozo) Kunth, Linnaea. 13: 579. 1839.

A velvety shrub; leaves subovate-elliptic, subacuminate, obtuse at base or slightly cordulate; 4 or 5 × 10 cm., pinnately nerved throughout; petiole 5 mm. long; racemes 10 × 60 mm.; peduncle 10 mm. long; pedicels fully 3 mm. long, exceeding the ovoid fruit.

Type locality: Mt. Corcovado, Rio de Janeiro (Guillemin 728; Gaudichaud 83, 1102).

Recognized for São Paulo in Mosén 1689.

Distribution: East-central Brazil.

OTTONIA APODOSTACHYA n. sp.

A nodose glabrous shrub; upper internodes rather elongated and slender; leaves subovate or broadly lanceolate, bluntly rather long-acuminate, rounded at base, 7 or 8 × 15–21 cm., pinnately nerved throughout, the nerves some 8 × 2 with several intermediates; petiole scarcely 5 mm. long; racemes 7 × 100 mm.; peduncle obsolete; pedicels twice as long as the flowers.

Type locality: Jaraguá, Sta. Catharina (Hoehne 24388).

Distribution: East-central Brazil.

OTTONIA APODOSTACHYA VIDALI n. var.

Glabrous; heterophyllous, the leaves from narrowly oblong and scarcely 2.5 × 9 cm. to lanceolate and 5.5 × 18 cm., or ovate-elliptic and 7 × 15 cm., rather long-attenuate, slightly inequi-laterally subcordulate; petiole and peduncle 4 mm. long; racemes 8 × 100 mm.; pedicels twice as long as the flowers.

Type locality: Espiritu Santo (José Vidal 138).

Distribution: East-central Brazil.

OTTONIA ARMONDI n. sp.

A nodose shrub with more or less persistently velvety twigs, petioles and nerves beneath; flowering internodes rather short and slender; leaves lanceolate, more or less falcately acuminate, obtuse at base or somewhat cordulate, 3–5 × 13 or 14 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole 5 mm. long; racemes some 8 × 70 mm.; peduncle 5 mm. long; pedicels twice as long as the ovoid fruits.

Type locality: Carmo, Rio de Janeiro (N. Armond 156).

Distribution: East-central Brazil.

Ottonia atrosanguinea (C.DC.) n. comb.

Piper atrosanguineum C.DC., Linnaea. 37: 338. 1872.

A generally glabrous shrub; leaves lanceolate, acuminate, the rounded base somewhat cordulate, 4 × 11–13 or 15 cm., pinnately nerved throughout, the nerves 10 or 12 × 2; petiole scarcely 5 mm. long; racemes subpuberulous, 5 × 60 or 70 mm.; peduncle 5 mm. long; pedicels equaling the oblong-ovoid papillate fruit.

Type locality: "Brazil" (Warming).
Distribution: East-central Brazil.

Ottonia baptisiana (C.DC.) n. comb.

Piper baptisianum C.DC., Prod. 16¹: 253. 1869.

A glabrous shrub; leaves elliptic-oblong, acuminate, the narrowed base slightly inequilaterally obtuse, 6 × 17 cm., pinnately nerved throughout; petiole 2 mm. long; racemes shorter than the leaves; pedicels equaling the fruits.

Type locality: S. João Baptisto, Minas Geraes (v. Martius).
Distribution: East-central Brazil.

Ottonia brevistipitata (C.DC.) n. comb.

Piper brevistipitatum C.DC., Linnaea. 37: 338. 1872.

A glabrous nodose shrub; flowering internodes short and moderately slender; leaves elliptic-lanceolate, acuminate, cordulate at the narrowed base, 2.5–5 × 8–12.5 cm., pinnately nerved throughout, the nerves 10 or 12 × 2; petiole 5 mm. long; racemes 5 × 40–70 mm.; peduncle 5 or 6 mm. long; pedicels almost suppressed; berries ovoid-acute, angular.

Type locality: Lagoa Santa, Minas Geraes (Warming, 12/24/63).
Distribution: East-central Brazil.

Though originally described from a sheet in the Candollean herbarium with leaves scarcely 3.5 × 13 cm. and younger racemes about 35 mm. long, it is represented at Copenhagen by a specimen with leaves 4 or 5 × 11–13 cm., and older racemes 45–65 mm. long; but even in this form it differs in more elongated leaves, shorter petiole and peduncles, and more obvious pedicels, from *O. leptostachya* of Rio, to which it evidently is closely related.

OTTONIA BURCHELLII n. sp.

A shrub, hirtellous throughout; flowering internodes slender; leaves oblong, acuminate, cordulate, 4 × 12 cm., pinnately nerved throughout; petiole 2 mm. long; racemes 10 × 40 mm.; peduncle 10 mm. long; pedicels considerably longer than the flowers.

Type locality: Mt. Corcovado, Rio de Janeiro (Burchell 1127, at Kew). Also: "Brazil" (?v. Martius 1210).

Distribution: East-central Brazil.

OTTONIA CARPINIFOLIA Presl, Epimel. 229. 1849.

Piper carpinifolium (Presl) C.DC., Prod. 16[1]: 255. 1869.

A shrub with velvety axes, petioles and leaf-nerves beneath; leaves lance-oblong, acuminate, equilaterally cordulate, 2–3.5 × 9 cm., pinnately nerved; petiole some 5 mm. long; racemes 28 mm. long; peduncle 2–4 mm. long; pedicels scarcely 1 mm. long, glabrous like the rachis.

Type locality: Rio de Janeiro (Beseke).
Distribution: East-central Brazil.

OTTONIA CLAUSSENI n. sp.

A glabrous scarcely granular herb; leaves lanceolate, gradually acute, the narrowed base cordulate, 3.5 × 11 cm.; petiole scarcely 5 mm. long; racemes 10 × 50 or 60 mm.; peduncle 5 mm. long; pedicels about 3 mm. long.

Type locality: Minas Geraes (Claussen in 1840, at Kew).
Distribution: East-central Brazil.

OTTONIA COLLICULORUM n. sp.

A glabrous shrub; flowering internodes slender, quickly elongating; leaves ovate- or lance-elliptic, gradually subacuminate, nearly equilaterally rounded at base, 3.5–4.5 × 8–10 cm., pinnately nerved throughout, the nerves some 8 × 2; petiole 5 mm. long; racemes 5 × 50 mm.; peduncle 5–8 mm. long; pedicels scarcely as long as the fruits.

Type locality: Morro do Carvalão (Schwacke 28315); also Morro de Babilonia (Hoehne 24733).
Distribution: East-central Brazil.

OTTONIA CONSANGUINEA Presl. Epimel. 230. 1849.

Piper punctatissimum C.DC., Prod. 16¹: 255. 1869.

A rusty-hirtellous or hairy shrub; leaves lance- or oblong-elliptic, acuminate, cordulate, 4 or 5 × 12 cm., pinnately nerved throughout, the nerves some 8 × 2, glabrescent above; petiole 5 mm. long; racemes 6 × 60 mm., peduncle 5 mm. long; pedicels surpassing the flowers.

Type locality: Mt. Corcovado, Rio de Janeiro (Mikan; also, Mendonça 669; Schwacke 8985 or 8785).

Distribution: East-central Brazil.

OTTONIA CORCOVADENSIS Miquel. Linnaea. 20: 175. 1847: Fl Brasil. 4¹. pl. 23.

Piper corcovadense (Miq.) C.DC., Prod. 16¹: 256. 1869.

A nodose glabrous shrub; flowering internodes rather slender and short; leaves lanceolate, acuminate. the narrowed base minutely cordulate, 3.5 × 11 cm., pinnately nerved throughout, the nerves 8 or 10 × 2; petiole 5 mm. long; racemes some 8 × 75 mm.; peduncle 5 mm. long; pedicels equaling the flowers.

Type locality: Mt. Corcovado, Rio de Janeiro (Pohl 4776: 5030). Also: Rio Parahyba (Schwacke 3349).

Distribution: East-central Brazil.

OTTONIA CORCOVADENSIS BLANCHETI (Moric.) n. comb.

Ottonia Blancheti Moricand, Pl. Nouv. Amer. 87. pl. 57. 1833–1846.
Piper corcovadense sessilifolium C.DC., Prod. 16¹: 255. 1869.
Serronia acuminata Moricand, Pl. Nouv. Amer. pl. 57. 1833–1846.

Leaves more elliptic, 4 × 12–6 × 16 cm., cordulate; petiole scant 2 mm. long; racemes 8 × 80 mm.

Type locality: Bahia (Blanchet 1094; 2958, 3519; Wawra & Waby 146).

Distribution: East-central Brazil.

OTTONIA CORDULATIFOLIA n. sp.

Piper ovatum Auct., as to Paraguay.

A glabrous shrub; flowering internodes moderate; leaves ovate, acuminate, the rounded base slightly inequilateral and cordulate, 9.5 or 10 × 18 or 20 cm., pinnately nerved throughout, the nerves

some 12 × 2; petiole 10 mm. long; racemes 10 or 12 × 125 mm.; peduncle 5 mm. long; pedicels equaling the round-ovoid granular fruits.

Type locality: Alto Paraná (Fiebrig 5625, at Kew). Also, Rio Yhu (Hassler 9475).

Distribution: Paraguay.

OTTONIA CORDULATIFOLIA HIRTELLA (C.DC.) n. var.

Piper ovatum hirtellum C.DC., in herb.

Axes and nerves beneath somewhat velvety; leaves 8 × 17 cm., narrowed to the cordulate base; petiole 10 mm. long; racemes some 10 × 90 mm., with pedicels equaling the ellipsoid fruits.

Type locality: Sierra de Maracayu (Hassler 5103; 5387).

Distribution: Paraguay.

OTTONIA DIVERSIFOLIA Kunth, Linnaea. 13: 578. 1839.

Piper Selloi C DC., Prod. 16¹: 252. 1869.

A shrub with rather slender and short at least transiently puberulent internodes: leaves oblong-lanceolate, gradually attenuate, the narrowed base obtuse, 3.5–4 × 13–15 cm., pinnately nerved throughout, the nerves some 10 × 2, puberulent or hirtellous on the nerves beneath; petiole 5 mm. long, puberulent; racemes some 8 × 40 or 50 mm.; peduncle 10 mm. long; pedicels equaling the round-ovoid angled fruits.

Type locality: Rio de Janeiro (Sellow). Also: Theresopolis (de Moura 788). Rio Novo, Minas Geraes (? Schwacke 1894).

Distribution: East-central Brazil.

OTTONIA DOUGLASII n. sp.

A glabrous somewhat glandular-granular shrub; leaves elongated, lance-ovate, gradually falcately long-acuminate, acute-based, 3 or 3.5 × 13 or 14 cm., pinnately nerved throughout; petiole 5–10 mm. long; racemes 8 × 50 or 60 mm.; peduncle 5 or 10 mm. long, pedicels nearly twice as long as the fruits, granular.

Type locality: Rio de Janeiro (Douglas, at Kew). Also, "Brazil" (Riedel).

Distribution: East-central Brazil.

Ottonia Dusenii n. sp.

A glabrous or sparingly and locally hirtellous shrub; flowering internodes rather slender and elongated; leaves polymorphic, lanceolate or typically subovate-elliptic. acuminate, obtuse-based, 7.5–10 × 15–20 cm., pinnately nerved throughout; petiole scarcely 5 mm. long; racemes 8–12 × 50 mm. or more; pedicels equaling or surpassing the fruits.

Type locality: Paraná (Dusén 10456). Also: Alexandra, Paraná (Dusén 8676, at Stockholm); also in Paraná: Guaratuba (Dusén 13778), Pradrium Merumly (Dusén 14091), Serra da Preta (Dusén 15326), and, with smaller leaves and racemes only 30 mm. long, Porto de Cisma (Dusén 524 *a*).

Distribution: East-central Brazil.

Ottonia Duseni heterophylla n. var.

Glabrous, or somewhat hirtellous on the nodes and petioles; leaves broadly elliptic and 6–8 × 10 cm., or lanceolate and 4–6 × 12–15 cm.; petiole 5 mm. long; racemes in flower scarcely 8 × 60 mm., the peduncle 5 mm. long.

Type locality: Pinhares, Paraná (Dusén 14506, at Stockholm).

Ottonia Duseni variifolia n. var.

Exceptionally slightly hirtellous about the nodes and on the petiole or midrib beneath; leaves elliptic-ovate and 8 × 15 cm., or lanceolate and 2 × 9 cm. becoming 5 × 15 cm.; racemes 10 × 55–130 mm.

Type locality: Jaguariahyna, Paraná (Dusén, Apr. 16, 1911, at Stockholm; also Dec. 30, 1914, and 9803 and 10059); and also in Paraná; Therezina (Dusén 11182) and Patrimonio (Dusén, Mar. 9, 1915).

Ottonia Edwallii n. sp.

A glabrous nodose shrub; flowering internodes slender and short but quickly elongating; leaves lanceolate to typically lance-elliptic or elliptic, acuminate, round-based, 4 × 11–7 × 15 cm., pinnately nerved throughout. the nerves about 10 × 2; petiole 5 mm. long; racemes some 6 × 30 mm.; peduncle 5 mm. long; pedicels little longer than the flowers.

Type locality: Ribeira de Iguapé, São Paulo (Loefgren & Edwall 2814 = 12679).

Distribution: East-central Brazil.

OTTONIA ELOCALIS n. sp.

A glabrous but locally somewhat glandular-granular nodose shrub; flowering internodes short and slender; leaves broadly lanceolate, acuminate, the narrowed base subequilaterally obtuse, 6 or 7 × 13–16 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole 3–5 mm. long; racemes 10 × 30–50 mm.; peduncle 5 mm. long; pedicels about equaling the ovoid pointed fruits.

Type locality: Unrecorded (Luederwaldt 12675).

Distribution: ? East-central Brazil.

OTTONIA EUCALYPTIFOLIA Kunth, Linnaea. 13: 582. 1839.

Piper eucalyptophyllum C.DC., Prod. 16¹: 252. 1869.—Sometimes spelled *eucalypti-phyllum.*

A nodose glabrous shrub; flowering internodes rather thick and short; leaves lanceolate, acuminate, acute-based, 3 or 4 × 14 or 15 cm., pinnately nerved throughout, the nerves some 10 or 12 × 2; petiole scant 5 mm. long; racemes 5 or 6 × 60 mm.; peduncle 10 or 15 mm. long, glandular-granular like the ellipsoid fruit.

Type locality: Rio de Janeiro (Gaudichaud 1100; St. Hilaire 29; Hagendorff 717; Peckott 81). Also, Corcovado (Guillemin 728; Schenk 1790). Rio Parahyba (Luschnath).

Distribution: East-central Brazil.

OTTONIA EUCALYPTIFOLIA GLAUCESCENS (C.DC). n. comb.

Piper eucalyptiphyllum glaucescens C.DC., Candollea. 1: 247. 1923.

A silvery-blue-green form, in the type region: Rio de Janeiro (Glaziou 6805).

OTTONIA FRUTESCENS (C.DC.) n. comb.

Piper frutescens C.DC., Linnaea. 37: 337. 1872.

A slender-twigged glabrous shrub; leaves subovate-elliptic, acuminate, oblique and obscurely subpeltate at base with the larger side rounded, 5.5 × 11.5 or 12 cm., pinnately nerved throughout; petiole 10 mm. long; racemes 7 × 50 or 60 mm.; peduncle scant 10 mm. long; pedicels about equaling the angular-ovoid fruits.

Type locality: Lagoa Santa, Minas Geraes (Warming in 1870).

Distribution: East-central Brazil.

OTTONIA FRUTESCENS MICROCARPA (C.DC.) n. comb.

Piper frutescens microcarpa C.DC., Linnaea. 37: 337. 1872.

A glabrous shrub of the aspect of *P. frutescens;* leaves elliptic-ovate, acuminate, obtuse and obscurely subpeltate at base. 7 × 15 cm., pinnately nerved throughout, the nerves some 10 × 2: petiole 10 mm. long; racemes about 8 × 125 mm.; peduncle 10 mm. long; pedicels twice as long as the round-ovoid apiculate fruits.

Type locality: Lagoa Santa, Minas Geraes (Warming in 1870, in the Candollean herbarium).

Distribution: East-central Brazil.

OTTONIA GIBBIMONTIS n. sp.

Piper padifolium corcovadense C.DC., Prod. 16^1: 253. 1869.

A glabrous shrub; leaves subovate-elliptic, rather long-acuminate, rounded at base, 5–6 × 14 cm., pinnately nerved throughout; petiole scarcely 5 mm. long; racemes as yet scarcely 3 × 40 mm., short-peduncled and with undeveloped pedicels.

Type locality: Sebastianopolis, Mt. Corcovado, Rio de Janeiro (v. Martius).

Distribution: East-central Brazil.

OTTONIA GIBBIMONTIS ACUTA n. var.

Leaves 6 × 13 cm., gradually acute but not acuminate; flowers on equilong pedicels.

Type locality: Top of Mt. Corcovado, Rio de Janeiro (Pohl 5030, at Vienna, as *Piper ovatum*).

Distribution: East-central Brazil.

OTTONIA GLAZIOUI n. sp.

A shrub, more or less puberulent even to rachis, pedicels and fruits; leaves lanceolate. gradually subacuminate, the narrowed base cordulate or connately subpeltate, 3 or 3.5 × 11–13 cm., pinnately nerved throughout: petiole scarcely 5 mm. long; racemes about 10 × 50 or 60 mm.; peduncle 5 mm. long; pedicels about 3 mm. long, rather exceeding the ellipsoid fruits.

Type locality: Rio de Janeiro (Glaziou 6001, at Berlin).
Distribution: East-central Brazil.

OTTONIA GRANDIFOLIA n. sp.

Piper Hayneanum macrophyllum C.DC., Prod. 16¹: 253. 1869.

A glabrous glandular-granular shrub; leaves ovate, subacuminate, rounded at base or cordulate, 9–11.5 × 20–21 cm., or, upwards, ovate-lanceolate and 5 × 15 cm., pinnately nerved, the nerves some 10 × 2, obscurely puberulent next the margin beneath; petiole about 5 mm. long; racemes 10–15 × 120 mm.; peduncle scant 10 mm. long; fruits ovoid.

Type locality: Minas Geraes (v. Martius).
Distribution: East-central Brazil.

OTTONIA HAMMARI n. sp.

A nodose glabrous shrub; leaves lanceolate or elliptic-sublanceolate, gradually subacuminate, round-based, 4–5.5 × 10–13 cm., pinnately nerved throughout, the nerves some 10 × 2; petiole scarcely 5 mm. long; racemes some 10 × 30 mm.; peduncle 5 mm. long; pedicels rather longer than the ovoid fruits.

Type locality: Cantareira, São Paulo (A. Hammar 4551 = 12669).
Distribution: East-central Brazil.

OTTONIA HOEHNEI n. sp.

A nodose glabrous shrub; flowering internodes slender and rather short; leaves subrhombic-lanceolate, sharply long-attenuate-acuminate, subcuneate, 4.5 or 5 × 12 or 13 cm., pinnately nerved throughout, the nerves about 10 × 2; petiole 5 mm. long; racemes 5 × 80–120 mm.; peduncle 5 mm. long; pedicels somewhat longer than the flowers.

Type locality: Butantan, São Paulo (F. C. Hoehne 2480). Also, Loefgren 1425 = 12672.
Distribution: East-central Brazil.

OTTONIA HOOKERIANA Miquel, Hook. Lond. Journ. Bot. 4: 470. 1842.

Piper Gardnerii C.DC., Prod. 16¹: 254. 1869.

A shrub with twigs and petioles puberulent when young; leaves oblong-lanceolate, acuminate, narrowed to the base, 2–4 × 14 or 15

cm., pinnately nerved throughout, the nerves some 10 × 2; petiole scarcely 5 mm. long; racemes 6 × 30 mm.; peduncle 5 mm. long; pedicels equaling the flowers.

Type locality: Minas Geraes (Gardner 5186).
Distribution: East-central Brazil.

OTTONIA ITUANA n. sp.

A glabrous shrub; flowering internodes short and slender; leaves subovate-elliptic, acuminate, cordulate-rounded at base, 7 or 7.5 × 14–16 cm., pinnately nerved throughout, the white nerves some 12 × 2; petiole scarcely 2 mm. long; racemes 8 × 90 mm.; peduncle 5 mm. long; pedicels scarcely twice as long as the ovaries.

Type locality: Itu, São Paulo (—— 18268, Mar. 25, 1897).
Distribution: East-central Brazil.

OTTONIA JANEIROENSIS (C.DC.) n. comb.

Piper janeiroense C.DC., Linnaea. 37: 339. 1872.

A glabrous shrub; flowering internodes slender and at first rather short; leaves lanceolate, acuminate, narrowed and subacute at base, some 2.5–4 × 11 cm.; petiole scarcely 5 mm. long; racemes some 8 × 100 mm.; peduncle 5 mm. long; pedicels longer than the round-ovoid fruits.

Type locality: Rio de Janeiro (Lund).
Distribution: East-central Brazil.

OTTONIA LANCIFOLIA n. sp.

A blue-green glabrous shrub; flowering internodes slender and rather elongated; leaves lanceolate, gradually long-attenuate, narrowed but obtuse at base, 3.5 or 4 × 13–15 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole 10 mm. long; racemes 8 or 10 × 70–90 mm.; peduncle 10 mm. long; pedicels about equaling the fruits.

Type locality: Viçosa, Minas Geraes (Mexia 4499).
Distribution: East-central Brazil.

OTTONIA LATILIMBA (C.DC.) n. comb.

Piper Selloi latilimbum C.DC., Notizbl. Bot. Gart. Berlin. 7: 464. 1917.

A glabrous slender-twigged shrub; leaves subrhombically lance-ovate, rather long-acuminate, round-based, 5 or 6 × 12 or 13 cm.,

pinnately nerved throughout; petiole scarcely 5 mm. long; racemes 5 × 70 mm.; peduncle 10 mm. long; pedicels scant twice as long as the flowers.

Type locality: "Brazil" (Glaziou 19865).
Distribution: East-central Brazil.

OTTONIA LEPTOSTACHYA Kunth, Linnaea. 13: 586. 1839.

Piper Boucheanum C.DC., Prod. 16¹: 254. 1869.

A nodose glabrous shrub; flowering internodes quickly elongating; leaves elliptic or lance-elliptic, acuminate, the base abruptly somewhat cordulate-acute, 5.5–6.5 × 14 or 15 cm., pinnately nerved throughout, the nerves some 10 or 12 × 2; petiole 10 mm. long; racemes 5 × 70 or 80 mm.; peduncle 5 mm. long; fruits flask-shaped, nearly sessile.

Type locality: "Brazil" (Sellow 720; 1189).
Distribution: East-central Brazil.

OTTONIA LOEFGRENI n. sp.

A glabrous shrub; flowering internodes slender and moderately short; leaves elliptic-ovate, rather abruptly sharp-acuminate, rounded at base, 5 × 10–9 × 17 cm., pinnately nerved throughout, the nerves about 10 × 2; petiole about 5 mm. long; racemes 9 × 70 or 80 mm.; peduncle 5 mm. long; pedicels twice as long as the flowers.

Type locality: Pirituba, São Paulo (Loefgren 1552 = 12681).
Distribution: East-central Brazil.

OTTONIA MACHADOENSIS (C.DC.) n. comb.

Piper machadoense C.DC., Prod. 16¹: 254. 1869.

A glabrous shrub; leaves lanceolate or subovate to lance-ovate, acuminate, acute or acutish at base, 4.5 × 14 cm., pinnately nerved throughout, the nerves 8 or 10 × 2; petiole very short (3 mm.); racemes nearly as long as the leaves; peduncle very short; pedicels twice as long as the flowers.

Type locality: Rio Machado, Minas Geraes (Lindberg).
Distribution: East-central Brazil.

OTTONIA MACROPHYLLA Kunth, Linnaea. 13: 583.　1839.

Piper Hayneanum C.DC., Prod. 16¹: 253.　1869.

A nodose glabrous shrub; flowering internodes slender and comparatively short; leaves lance-elliptic, attenuate-acuminate, round-based or the upper acutish, 6.5–8 × 18 or 20 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole 10 or 15 mm. long; racemes 16 × 60 mm.; peduncle 5 mm. long; pedicels rather exceeding the flowers.

Type locality: Rio de Janeiro (Sellow; Widgren): also; Tejuca (Ule 4472); Theresopolis (de Moura 988, 991, 994, 996).

Distribution: East-central Brazil.

OTTONIA MACROSTACHYA Mart. in Miquel, Linnaea. 20: 176. 1847; Fl. Brasil. 4¹. pl. 22.

Piper sebastianopoliiense C.DC., Prod. 16¹, 252.　1869.

A glabrous nodose shrub; leaves lance-elliptic, acuminate, acute-based, 7 × 20 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole 10 or 15 mm. long; racemes 10 or 15 × 125 mm.; peduncle 10 mm. long; pedicels granular, longer than the granular fruits.

Type locality: Sebastianopolis, Rio de Janeiro (v. Martius): also; Corcovado (Miers 3289). Rio (Riedel 16; Glaziou 6004, 8074).

Distribution: East-central Brazil.

OTTONIA MARTIANA Miquel, Linnaea. 20: 178.　1847.

Piper Miquelianum C.DC., Prod. 16¹: 254.　1869.

A shrub, scarcely 2 m. tall, from generally puberulent glabrescent; leaves ovate- or broad-elliptic, long-acuminate, cordulate; 6 × 12 or 13 cm., pinnately nerved throughout, the nerves about 8 × 2; petiole 3–4 mm. long; racemes 40 or 50 mm. long; peduncle 5 mm. long; pedicels elongated.

Type locality: "Brazil" (von Martius).

Distribution: ? East-central Brazil.

OTTONIA MENDONCAE n. sp.

A glabrous shrub, glandular-granular even to the pedicels; leaves lance-elliptic, acuminate, rounded at base, 5.5 × 14 cm.,

pinnately nerved throughout, the nerves about 10 × 2; petiole scant 5 mm. long; racemes 10 × 35 mm.; peduncle 5 mm. long; pedicels about 3 mm. long.

Type locality: Mt. Corcovado, Rio de Janeiro (Mendonça 669, p.p. at Berlin).

Distribution: East-central Brazil.

OTTONIA MEXIAE n. sp.

A nodose shrub, 1 m. tall; flowering internodes slender and rather short, sparsely hirtellous; leaves ovate-elliptic or lanceolate, acuminate, obscurely cordulate, 4 × 10–6 × 12 cm., firm and paler beneath, pinnately nerved throughout, the nerves, 8 or 10 × 2, puberulent beneath; petiole 3 mm. long, hirtellous; racemes 10 × 45 mm.; peduncle 5 mm. long, hirtellous like the rachis and pedicels which are scarcely longer than the fruits.

Type locality: Barbada, Viçosa, Minas Geraes, at 680 m. (Ynes Mexia 5160).

Distribution: East-central Brazil.

OTTONIA MEXIAE FERTILIOR n. var.

Leaves more prevailingly lance-elliptic; racemes 12 × 70–100 mm., with pedicels twice as long as the fruits.

Type locality: Barbada, at 710 m. (Mexia 4587; 4619).

OTTONIA MIGUELITENSIS n. sp.

A small nodose glabrous blue-green shrub; flowering internodes rather slender but typically short; leaves rhombic-elliptic to lanceolate, subacuminate, obtuse-based, 3.5–5 or 6 × 10–12 or 14 cm., pinnately nerved throughout, the nerves some 10 × 2, drying hard; petiole 5 mm. long; racemes 8 × 60–90 mm.; peduncle scant 5 mm. long; pedicels scarcely equaling the fruits.

Type locality: São Miguel road, Viçosa, Minas Geraes, at 690 m. (Mexia 4964, 4964 *a*); also, above Viçosa, nos. 4702, 4373a, 4499, 4137, 4676).

Distribution: East-central Brazil.

OTTONIA MIGUELITENSIS LONGIPES n. var.

A more lanceolate-foliaged sparsely hirtellous form with leaves 2.5–6 × 11–15 cm., the racemes 10 × 80 mm., and the pedicels longer than the fruits.

Type locality: Fazenda de Guaciuma, Viçosa, at 700 m. (Mexia 4702).

OTTONIA MIGUELITENSIS PARCEPILOSA n. var.

A very variable shrub with very sparingly hirtellous axes; leaves rhombic-elliptic and as much as 8 × 15 cm. or lanceolate and 4–6 cm. wide; racemes 8 × 60–120 mm. with peduncle and pedicels as in the type.

Type locality: Areponga to São Miguel road (Mexia 4676 *b* and *a*).

OTTONIA MOSENII n. sp.

A glabrous shrub; flowering internodes slender and rather short; leaves subovate or upwards lanceolate, gradually acute rather than acuminate, somewhat convallately acute at base, 5–7 × 14–16 cm., pinnately nerved throughout, the nerves about 10 × 2 with some intermediates, paler beneath and drying chartaceous; petiole 5–10 mm. long; racemes some 5 × 65 mm.; peduncle 4 mm. long; pedicels twice as long as the young ovaries.

Type locality: Serra de Caracol, São Paulo (Mosén 1689, at Stockholm).

Distribution: East-central Brazil.

OTTONIA MUELLERI n. sp.

A transiently puberulent or glabrous shrub; flowering internodes moderate; leaves ovate or elliptic-ovate, acuminate, obtuse-based, 8.5 or 9 × 17 or 18 cm., pinnately nerved throughout, the nerves 8 or 10 × 2; petiole 5 mm. long; racemes scarcely 8 × 60 or 70 mm.; peduncle 5 mm. long; pedicels at length surpassing the flowers.

Type locality: Blumenau, Sta. Catharina (Fritz Mueller 459: Dr. Guill. Mueller in 1884, at Berlin).

Distribution: East-central Brazil.

OTTONIA NOVAESII n. sp.

A glabrous shrub; flowering internodes rather short and slender; leaves lance-elliptic, acuminate, acute-based, 6–6.5 × 14 or 15 cm., pinnately nerved, drying pale and coriaceous, convallate at base; petiole 5 mm. long; racemes 7 × 40 mm. or more; peduncle scant 5 mm. long; ovaries subovoid, gradually exceeded by the elongating pedicels.

Type locality: Campinas, São Paulo (José de Campos Novaes 504, in the U. S. National Herbarium).

Distribution: East-central Brazil.

OTTONIA OVATA (Vahl) n. comb.

Piper ovatum Vahl, Eclog. 3. pl. 1. 1796.
Ottonia Vahlii Kunth, Linnaea. 13: 565. 1839.

A nodose glabrous shrub; flowering internodes moderately stout and short; leaves elliptic-ovate, acuminate, rather abruptly subacute at base and cordulate, 7 or 8 × 15 or 16 cm., pinnately nerved throughout, the nerves some 8 × 2; petiole 5 mm. long; racemes 8 × 50 or 60 mm.; peduncle 10 mm. long; pedicels equaling the ovoid papillate fruits.

Type locality: Trinidad (Ryan).

Distribution: Trinidad, in the Leeward Islands.

OTTONIA OVATA STENOSTACHYA n. var.

Leaves cordulate but scarcely narrowed at base; petiole and peduncle 5 mm. long; racemes 5 mm. in diameter.

Type locality: Trinidad (Fendler 669, at Paris).

OTTONIA PADIFOLIA Kunth, Linnaea. 13: 580. 1839.

Piper padifolium (Kunth) C.DC., Prod. 16¹: 253. 1869.

A glabrous nodose shrub; flowering internodes slender and moderately short; leaves oblong- or subovate-elliptic, acuminate, rounded at base and slightly cordulate, 3 or 3.5 × 6.5–9.5 cm., pinnately nerved throughout, the nerves 6 or 8 × 2; petiole almost suppressed; racemes short (10 × 20 mm.); peduncle 10 mm. long; pedicels 3 mm. long, about equaling the round-ovoid apiculate fruits.

Type locality: "Brazil" (Sellow 230, 716). Also; Organ Mountains (Gardner 5862).

Distribution: East-central Brazil.

OTTONIA PALHOSANA n. sp.

A glabrous shrub; upper internodes rather slender and sub-elongated; leaves elliptic, sharp-acuminate, rounded at base or downwards subobliquely acute, 7.5 × 15 cm., pinnately nerved throughout, the nerves some 12 × 2 with intermediates; petiole 10 mm. long; racemes 10 × 60 or 80 mm.; peduncle 10 mm. long; pedicels about twice as long as the flowers.

Type locality: Palhoça, Florianopolis (Hoehne 24462).
Distribution: East-central Brazil.

OTTONIA PERUIBENSIS n. sp.

A glabrous shrub; flowering internodes rather short and slender; leaves ovate- or subrhombic-elliptic, acuminate, somewhat inequi-laterally obtuse at base, 6.5 × 14–8 × 15 cm., pinnately nerved throughout, the nerves some 10 × 2 with intermediates; petiole 5–10 mm. long; racemes some 10 × 40 mm.; peduncle 5 mm. long; pedicels twice as long as the conic-ovoid fruits.

Type locality: Peruibe, São Paulo (Loefgren 1625 = 12677).
Distribution: East-central Brazil.

OTTONIA PRAECOX (C.DC.) n. comb.

Piper praecox C.DC., Ann. Conserv. Genève. 2: 254. 1898.

A dwarf shrub, glabrous except for the transiently puberulent twigs and nerves of the leaves; leaves lance-elliptic, acuminate, obtuse-based or cordulate, 3 or 3.5 × 7–10 cm., pinnately nerved throughout, the nerves some 8 × 2; petiole scarcely 5 mm. long; racemes scarcely 5 × 50 mm.; peduncle scant 5 mm. long; pedicels about equaling the round fruits.

Type locality: Minas Geraes (Weddell).
Distribution: East-central Brazil.

OTTONIA PROPINQUA Kunth, Linnaea. 13: 583. 1839.

A glabrous nodose shrub; flowering internodes slender and moderately short; leaves ovate- or elliptic-oblong, acuminate, inequilaterally rounded at the narrowed base, 5 or 6 × 13 or 14 cm., pinnately nerved throughout; petiole scant 5 mm. long; racemes 5 × 80 mm.; peduncle 5 mm. long; pedicels some 2 mm. long; fruits round-ovoid.

Type locality: "Brazil" (Sellow 232).
Distribution: East-central Brazil.

OTTONIA PTEROPODA MORICAND, Pl. Nouv. Amer. 88. 1833–1846.

Piper pteropodon (Mor.) C.DC., Prod. 16¹: 255. 1869.

A shrub, with axes petioles and nerves beneath velvety; leaves oblong-elliptic, acuminate, rounded at base or cordulate, about 4 × 10 or 11 cm., pinnately nerved throughout, the nerves about 10 × 2; petiole 3 mm. long; racemes some 5 × 35 mm.; peduncle 5 mm. long; pedicels longer than the flowers.

Type locality: Bahia (Blanchet 1960; 1946, and without number at Paris).
Distribution: East-central Brazil.

OTTONIA RIEDELII n. sp.

A shrub?; glabrous; flowering internodes short and slender; leaves subovate-lanceolate, acuminate, rounded at base, some 3–4 × 8–10 cm.; racemes 5 × 60–70 mm.; peduncle 5 mm. long; pedicels longer than the flowers.

Type locality: "Brazil" (Riedel).
Distribution: East-central Brazil.

OTTONIA RIO-FEIOANA n. sp.

A nodose glabrous shrub; upper internodes short and slender; leaves broadly lanceolate or lance-elliptic, gradually subacuminate, the narrowed base commonly obtuse on one side, 4.5–6 × 11–14 cm., pinnately nerved throughout, the nerves about 10 × 2; petiole 5–8 mm. long; racemes 10 × 40–70 mm.; peduncle 10 mm. long; pedicels twice as long as the flowers.

Type locality: —— (Rio Feio expedition 12666).
Distribution: East-central Brazil.

OTTONIA SANTA-ANNAE n. sp.

A glabrous shrub; flowering internodes rather short and slender; leaves oblong-lanceolate and 3 × 10 cm. or lance-elliptic and 5 × 14 cm., acuminate, rounded or obscurely cordulate at base, pinnately nerved throughout, the nerves some 10 × 2; petiole scarcely 5 mm. long; racemes 10 × 50 mm., closely flowered; peduncle scarcely 5 mm. long; pedicels about equaling the ovoid maturing fruits.

Type locality: Sta. Anna, São Paulo (—— 5786 = 7183).
Distribution: East-central Brazil.

OTTONIA SANTA-RITANA n. sp.

A slender-twigged shrub with axes, nerves beneath and even fruits microscopically papillate-puberulent; leaves lance-elliptic, acuminate, acute-based, 4–6 × 11–14 cm., pinnately nerved throughout; petiole scant 5 mm. long; racemes 10 × 30 mm.; peduncle 5 mm. long; pedicels twice as long as the round-ovoid fruits.

Type locality: Santa Rita, Minas Geraes (Schwacke 11326, in the Candollean herbarium). Also, Serra dos Orgãos (no. 4289).

Distribution: East-central Brazil.

The type number at Berlin is not appreciably puberulent and has racemes 60 mm. long.

OTTONIA SANTA-LUDOVICIANA n. sp.

Ottonia propinqua f. Miquel, Fl. Brasil. 4¹: 66. 1852.

A glabrous shrub; leaves rhombic, gradually subacuminate, the narrow base obscurely auriculate, 6.5 × 16 cm., pinnately nerved throughout; petiole 5 mm. long; racemes 8 × 40 mm.; peduncle nearly 10 mm. long; pedicels shorter than the ovoid fruits.

Type locality: S. Ludovicus island, Maraguani (von Martius).

Distribution: ? East-central Brazil.

OTTONIA SCHWACKEAE n. sp.

A shrub; glabrous, or the midrib beneath and the peduncle sparsely and fugaciously hirtellous; twigs slender; leaves sub-rhombically elliptic, acuminate, gradually acute at base but minutely cordulate, 6 × 14 cm., pinnately nerved throughout, the nerves about 8 × 2; petiole scarcely 5 mm. long; racemes 5 × 30 mm.; pedicels about twice as long as the flowers.

Type locality: Blumenau, Sta. Catharina (Anna Schwacke 5038, in the Candollean herbarium). Also, S. Francisco, Sta. Catharina (Ule 200).

Distribution: East-central Brazil.

OTTONIA STATIONIS n. sp.

A glabrous shrub; flowering internodes moderately stout and elongated; leaves lance-elliptic, acuminate, slightly cordulate at the

rounded base, 6.5 × 19 cm., pinnately nerved throughout, the nerves some 12 × 2; petiole scarcely 5 mm. long; racemes 10 × 60 mm.; peduncle 5–10 mm. long; pedicels much longer than the ellipsoid angled fruits.

Type locality: Bahia (Blanchet, without number, at Paris).

Distribution: East-central Brazil.

OTTONIA STRIATICAULIS n. sp.

A shrub, somewhat velvety upwards; twigs sulcate, transversely striate; leaves narrowly lanceolate, very gradually pointed from the middle, acute-based, 3 × 13 cm., pinnately nerved throughout; petiole 5 mm. long; racemes 5 × 20 mm. (? or longer); peduncle 5 mm. long; pedicels about as long as the flowers.

Type locality: Tunela (Hb. Endlicher). Also, Locaja (Mikan).

Distribution: —— Brazil.

OTTONIA SUBGLAUCA (C.DC.) n. comb.

Piper subglaucun C.DC., Linnaea. 37: 337. 1872.

A glabrous nodose shrub: flowering internodes slender and rather short; leaves elliptic or subovate-elliptic, 5 or 6 × 10 or 12 cm., pinnately nerved throughout, the nerves some 10 × 2, coriaceous, pale beneath; petiole scarcely 5 mm. long; racemes 8 × 70 mm.; peduncle scarcely 5 mm. long; pedicels about equaling the acutely ovoid angled fruits.

Type locality: —— (Warming 1/28/64).

· *Distribution:* East-central Brazil.

OTTONIA TAPERANA n. sp.

A somewhat nodose glabrous shrub; twigs slender and moderately elongated, darkening; leaves variable, lance-oblong and 3.5 × 12 cm., broadly lanceolate and 5.5 × 15 cm., or lance-ovate and 5 × 12 cm., acuminate, obtuse-based, pinnately nerved throughout, the nerves some 8 × 2; petiole scarcely 5 mm. long; racemes 7 × 60 or 70 mm.; peduncle 10 mm. long; pedicels 2 mm. long, exceeding the young fruits.

Type locality: Palmares, Tapéra, Pernambuco (Pickel 2789, in the U. S. National Herbarium as sheet 1541640).

Distribution: Northeastern Brazil.

OTTONIA USTERII n. sp.

A glabrous shrub; upper internodes rather short and slender, becoming striate-ridged; leaves elliptic or subovate-elliptic, more or less acuminate, obtuse-based, 5×10–7.5×13 cm., pinnately nerved throughout, the nerves about 10×2, paler beneath; petiole 2 or 3 mm. long; racemes 7×40 mm.; peduncle scant 5 mm. long; pedicels twice as long as the flowers.

Type locality: São Caetano, São Paulo (A. Usteri 12683, Nov. 16, 1907, at the Instituto Biologico, S. Paulo).

Distribution: East-central Brazil.

SPECIES EXCLUDED FROM OTTONIA

Ottonia Carpunya Miquel	*Piper Carpunya*
Ottonia glaucescens Miquel	*Piper darienense*
Ottonia Klotzschiana Kunth	*Piper Kunthianum*
Ottonia laeta Kunth	*Piper Hoffmannseggianum*
Ottonia Lessertiana Miquel	*Piper Lessertianum* C.DC. 1869. Not C.DC. 1864
Ottonia Pohliana Miquel	*Piper Hoffmannseggianum*
Ottonia punctata Grisebach	*Piper cubanum*
Ottonia sphaerocarpa Grisebach	*Piper sphaerocarpum*
Ottonia stipulacea Presl	*Arctottonia stipulacea*
Ottonia unguiculata Heynl.	*Piper unguiculatum, fide* Ind. Kew.
Ottonia Warakabacourana Miquel	*Piper Warakabacourana.*

THE SPECTRUM OF NOVA HERCULIS IN THE VISUAL REGION

N. T. BOBROVNIKOFF

INTRODUCTION

NOVA HERCULIS was discovered by J. M. Prentice, of Stowmarket, England, on the morning of December 13, 1934. It appeared at the worst possible time of the year so far as observing conditions were concerned. The right ascension of the sun was only one hour less than that of the Nova at its discovery. During the first part of the period of the Nova's naked eye visibility from December 13, 1934 to the beginning of April, 1935 it could be observed only immediately after sunset or just before sunrise. Had it appeared half a year later it could have been observed the whole night.

Nova Herculis differed considerably in its behavior from other novæ studied heretofore. It reached its primary maximum of first magnitude by December 23, 1934. Two days later it dropped two magnitudes after which it fluctuated between second and third magnitude for a whole month. After a drop to the magnitude of 3.7 on January 30, it rose again to second magnitude by February 6. After that date it declined in brightness with numerous fluctuations, slowly for a month and very rapidly after April 1, 1935. After sinking to thirteenth magnitude early in May, it brightened up again to a secondary maximum of 6.5 magnitude in the middle of August. This behavior of Nova Herculis was in many ways parallel to Nova Aurigæ of 1891, but differed from the rest of the novæ in its great decrease in brightness between the beginning of April and the middle of July, 1935.

The spectrum of Nova Herculis was unusual in the early appearance of the forbidden lines of neutral oxygen which appeared a few days after the primary maximum. The

presence of the cyanogen [1] and Swan [2] absorption bands near the time of maximum is wholly unprecedented.

Finally, the discovery of the duplicity of Nova Herculis makes it a new star of exceptional interest. Only one other object of this kind, namely Nova Pictoris,[3] showed two or even three components.

Our information on such a transient celestial phenomenon as a nova is necessarily fragmentary. Therefore all material on the nova, however scant it may be, is of interest. It is of course premature to construct an elaborate theory to explain the puzzling features of the nova until all the available material is studied and published. However, some understanding of the nature of these mysterious objects can be gained by a careful study of the spectrographic material obtained at any one observatory.

At the Perkins Observatory the first spectrogram of the Nova was made on the morning of January 5. Altogether 30 spectrograms on 17 nights were obtained in the interval between January 5 and March 31, 1935.

Since it was evident that most observatories would concentrate their efforts on obtaining spectrograms in the photographic region, it was decided to study the spectrum of the nova primarily in the visual part of the spectrum between H_α and H_β.

The main purpose of this paper is a detailed study of the structure and behavior of prominent emission and absorption bands in the visual part of the spectrum. In Nova Herculis these features include the radiations of oxygen, hydrogen, sodium and ionized iron. An investigation of fainter bands and lines must be left for the future.

The list of the plates is given below in table 1.

These plates were obtained with the Yerkes auto-collimating spectrograph attached to the 69-inch Perkins reflector. All plates except Nos. 8 and 9 were taken on 1F Eastman

[1] Sanford, *Publ. A.S.P.*, **47**, 209, 1935.
[2] Lindblad and Öhman, *Stockholms Meddelande*, No. 19, 1935.
[3] Spencer Jones, *Annals Cape Observatory*, **10**, part 9, 1931.

TABLE 1

LIST OF PLATES

No.	Obs. No.	Mid-Exp. U T. 1935	Duration of Exp.	Observer	Remarks
1	Y170	Jan. 5.492	47^{m}	B	
2	Y171	Jan. 5.514	12	C; B	
3	Y172	Jan. 11.492	34	B; Hy	
4	Y173	Jan. 11.513	16	B; Hy	
5	Y175	Jan. 12.483	30	B; Hy	
6	P477	Jan. 18.476	60	Hy	
7	P478	Jan. 18.506	12	Hy	
8	P479	Jan. 18.513	7	Hy	Film 3F
9	P481	Jan. 23.500	35	Hy	Prism, Hyperpress
10	P482	Jan. 23 547	50	Hy	
11	P488	Jan. 28.490	50	Hy	
12	P489	Jan. 30.464	65	Hy	
13	Y176	Jan. 30.502	35	Hy	
14	P491	Jan. 31.446	67	Hy	
15	Y177	Jan. 31.493	60	Hy	
16	Y179	Feb. 2.422	15	C	
17	P494	Feb. 6.455	90	Hy	
18	P495	Feb. 6.499	30	Hy	
19	Y180	Feb. 7.466	57	B	
20	P497	Feb. 13.414	68	H	
21	Y181	Feb. 13.465	75	C	
22	Y182	Feb. 24.397	90	C; B	
23	Y183	Feb. 24.446	40	C; B	
24	Y184	Feb. 24.477	40	C; B	
25	P508	Mar. 1.441	80	H	
26	Y185	Mar. 2.413	120	C	
27	Y186	Mar. 2.469	30	C	
28	Y187	Mar. 9.376	150	C	
29	Y188	Mar. 9.455	70	C	
30	Y189	Mar. 30.373	235	C	

emulsion with a grating, giving an average dispersion of 26.6 A per mm. The region between H_α and H_β is in good focus. These lines are overexposed on all the spectrograms which show a continuous spectrum.

Observers are Bobrovnikoff (B), Hynek (Hy), Cobb (C), Henyey (H).

All the wave-lengths have been reduced to the sun, and are expressed in I. A. The displacement factor κ given for absorption lines is $(\Delta\lambda/\lambda)10^4$. The corresponding radial velocities are $v = 30 \, \kappa$ in km./sec.

In the following description of the spectrum frequent reference has been made, for purposes of economy of space, to the "*violet*" and "*red*" sides or components of spectral lines. These expressions make little sense when the whole line is situated in the red part of the spectrum. This is merely an effort to avoid such cumbersome phrases as "the side of the line toward the shorter (or longer) wave-lengths."

NEUTRAL OXYGEN

The most striking feature of the spectrum of the Nova in the visual region during the period under consideration was the emission lines due to forbidden transitions in neutral oxygen. According to Bowen [1] the transitions and wave-lengths are as follows:

TABLE 2

Transition	λ	Occurrence
$^3P_1 - {}^1S$	2972.31	Never observed
$^1D - {}^1S$	5577.34	Aurora line
$^3P_2 - {}^1D$	6300.23	Observed in nebulæ
$^3P_1 - {}^1D$	6363.88	Observed in nebulæ

In the spectrum of the Nova the three latter lines were present during the whole period of observation. The aurora line was comparatively faint but the other two were among the strongest in the whole spectrum, $\lambda 6300$ being always considerably stronger than $\lambda 6363$.

These forbidden lines emerged [2] in the spectrum of the Nova on December 25, 1934. On the first plate of our series, January 5.492, the lines are distinctly visible, but $\lambda 6363$ cannot be measured on account of heavy absorption lines at $\lambda\lambda 6354.4$, 6365.9 and 6371.2.

On the first plate the lines, or rather bands, $\lambda 6300$ and $\lambda 5577$ are in emission, without a trace of absorption associated with them. They are about 12 A in width and do not show much structure, except for the fact that the red edge is somewhat stronger than the violet.

Very soon the edges of these lines become pronounced.

[1] *Ap. J.*, **81**, 1, 1935.
[2] Stoy and Wise, *Publ. A.S.P.*, **47**, 61, 1935.

They are plainly visible on the spectrogram of January 12. Generally speaking the middle of the lines was getting weaker in comparison with the edges as the time went on, although there were occasional departures from this rule.

TABLE 3

FORBIDDEN OXYGEN

Emission 1

Date	λ 6363		λ 6300		λ 5577	
	W	Δλ	W	Δλ	W	Δλ
Jan. 5.492..	—	—	12.14	−0.16	11.47	+0.78
Jan. 5.514.....	—	—	12.43	−0.34	—	—
Jan. 11.492	12.45	−0.85	12.52	−0.46	10.86	−0.16
Jan. 11.513	—	—	12.67	−0.53	—	—
Jan. 12.483	—	—	12 88	−0.06	—	—
Jan. 18.476.............	—	—	12.63	−0.26	—	—
Jan. 18.506......	—	—	12.48	−0.61	—	—
Jan. 23.547.	13.53	−1.01	13.56	−0.51	11.93	+0.75
Jan. 28.490	14.03	−0.43	14.15	−0.59	—	—
Jan. 30.464	15.19	−0.55	14.98	−0.56	13.52	−0.36
Jan. 30.502	15.40	−0.53	14.61	−0.14	14.56	−0.30
Jan. 31.446	15.21	−0.84	15.01	−0.89	13.38	−0.56
Jan. 31.493.............	14.70	−0.65	14.68	−0.51	13.55	−0.10
Feb. 2.422.............	15.32	−0.69	14.89	−0 30	—	—
Feb. 6.455	16.56	−0.42	15.66	−0.29	14.89	−0.25
Feb. 6.499	15.03	+0.55	14.97	−0.55	—	—
Feb. 7.466	15.79	−0.45	15.19	−0.24	14.38	−0.54
Feb. 13.414	16.82	−0.41	16.12	−0.73	—	—
Feb. 24.397.....	16.32	−0.15	16.42	−0.82	15.24	−0.61
Feb. 24.446	17.01	+0.23	16.51	−0.24	—	—
Feb. 24.477..	16.19	+0.01	16.25	−0.24	15.88	−0.23
Mar. 1.441	—	—	15.76	−0.75	—	—
Mar. 2.413	16.36	−1.05	15.70	−0.50	14.24	−0.24
Mar. 2.469.	15.76	−0.59	15.56	−0.40	—	—
Mar. 9.376	16.08	−0.28	16.01	−0.25	14.43	−0.37
Mar. 9.455	16.25	−0.84	16.12	−0.45	—	—
Mar. 30.373	16.34	−0.44	16.43	−0.30	—	—

Emission 2

Date	λ 6363		λ 6300		λ 5577	
Jan. 30.464..............	38.7	−0.8	40.3	−0.6	—	—
Jan. 30.502	38.2	−0.5	40.9	−0.2	40.7	+0.7
Jan. 31.446.	40.1	−0.7	39.3	−0.5	39.4	−0.2
Jan. 31.493	38.7	−1.3	37.3	−0.6	35.7	−0.5
Feb. 6.455.	—	—	41.7	+0.3	—	—
Feb. 7.466......... ...	—	—	41.4	−0.4	—	—

It soon became evident that the width of the oxygen lines was increasing. The lines, especially λ 6300, were so sharply defined that it was possible to measure their width accurately. Table 3 gives the results of measurement. Under the heading *W*, Emission 1, are given the widths of the lines in angstroms measured from the outer edge of the shorter wave-length component to the outer edge of the longer wave-length component. This of course is not the true width of the lines as the effect of the photographic spreading must be taken into account. The half-widths of comparison lines of approximately the same intensity and situated in the vicinity of the oxygen lines are given in table 4 in columns marked with *C*. The true width of the lines can be obtained from the data of table 3 by applying twice the value of the correction *C*. It was found, however, that the general curve of the width does not appreciably change its shape when this correction is applied but is merely shifted down. Since other emission lines were not so well defined as the oxygen lines and the correction for spreading would make little difference in that case it was decided not to apply this correction at all. It is given in table 4 for the convenience of those who might wish to compare my results with the results obtained at other observatories.

It is seen from Figure 1 that all three lines of neutral oxygen show a very similar variation in width. From the beginning of the observational period they steadily increased in width slowly at first and faster later until the peak was reached in the middle of February. After this there was a decrease in width with a secondary minimum near the middle of March. The last measure of March 31 shows again an increase in width. The most consistent curve is that of λ 6300 which is natural enough since this line was the sharpest and strongest of the three.

It looks, at least so far as the available material is concerned, as if the growth of the bands in width can be represented by a line with a superimposed sinusoid. In three months just one cycle was covered. For λ 6300 the straight

TABLE 4

FORBIDDEN OXYGEN

Width and Intensity of the Components

$i_V = 10$

Date	λ 6363				λ 6300				λ 5577			
	W_V	W_R	C	i_R	W_V	W_R	C	i_R	W_V	W_R	C	i_R
Jan. 5.492	—	—	—	—	—	—	0.44	12	—	—	0.32	12
Jan. 5.514	—	—	—	—	—	—	0.41	12	—	—	—	—
Jan. 11.492	—	—	0.33	12	1.60	1.37	0.35	8	—	—	0.27	10
Jan. 11.513	—	—	—	—	—	—	0.55	8	—	—	—	—
Jan. 12.483	—	—	—	—	2.47	2.94	0.44	12	—	—	—	—
Jan. 18.476	—	—	—	—	1.20	2.07	0.37	8	—	—	—	—
Jan. 18.506	—	—	—	—	—	—	0.42	8	—	—	—	—
Jan. 23.547	—	—	0.29	10	1.99	2.92	0.40	12	—	—	0.36	9
Jan. 28.490	—	—	0.69	10	1.59	1.96	0.40	12	—	—	—	—
Jan. 30.464	3.05	3.49	0.66	8	2.74	2.70	0.66	8	2.98	3.55	0.48	10
Jan. 30.502	2.95	2.86	0.60	7	2.11	2.49	0.60	7	2.97	3.36	0.63	7
Jan. 31.446	3.05	2.70	0.60	8	2.88	3.13	0.87	7	2.68	2.72	0.38	8
Jan. 31.493	4.26	3.41	0.47	10	2.86	3.35	0.58	8	3.53	3.28	0.54	12
Feb. 2.422	—	—	0.52	8	2.19	2.38	0.52	8	—	—	—	10
Feb. 6.455	—	—	0.54	8	3.12	3.53	0.54	8	3.42	2.59	0.58	8
Feb. 6.499	—	—	0.61	12	3.23	3.23	0.61	12	—	—	—	12
Feb. 7.466	—	—	0.55	12	2.77	3.44	0.55	10	—	—	0.43	12
Feb. 13.414	—	—	0.46	15	3.93	3.70	0.46	8	—	—	—	—
Feb. 24.397	3.00	3.51	0.95	8	3.26	3.83	1.03	8	3.34	3.40	0.55	8
Feb. 24.446	2.99	3.62	0.55	8	3.46	3.52	0.66	8	—	—	—	—
Feb. 24.477	3.20	4.64	0.52	10	3.47	3.40	0.60	10	3.09	4.74	0.60	10
Mar. 1.441	—	—	—	—	3.50	4.03	0.71	—	—	—	—	—
Mar. 2.413	3.75	3.29	0.72	10	2.57	3.17	0.72	7	2.97	2.91	0.45	10
Mar. 2.469	3.42	3.59	0.62	12	2.75	3.24	0.60	7	—	—	—	—
Mar. 9.376	2.70	2.45	0.59	7	2.41	2.83	0.54	7	2.18	2.37	0.43	8
Mar. 9.455	3.41	4.30	0.52	7	2.88	3.17	0.61	7	—	—	—	—
Mar. 30.373	3.13	3.40	0.45	2	3.20	3.54	0.45	5	—	—	—	—

line would give the increase of 0.049 A per day with an amplitude of the three months' variation of about 2 A. Translated into acceleration, the half increase in width, 0.0245 A, would give 1.17 km./sec. per day[2].

The displacements of the centers of the oxygen lines are given in table 3, columns $\Delta\lambda$. Assuming all the plates to be of equal weight, the average displacement for λ 6300 is — 0.43 ± 0.14 A, and for λ 6363 — 0.47 ± 0.28, giving the corresponding velocities of approach in the first case 20.6 ± 6.6

km./sec. and in the second 22.3 ± 12.8 km./sec. Taking the
weights of these two series as inversely proportional to their
probable errors we have the velocity of approach for OI as
21.2 km./sec. which is the exact mean of the velocity of 21.0
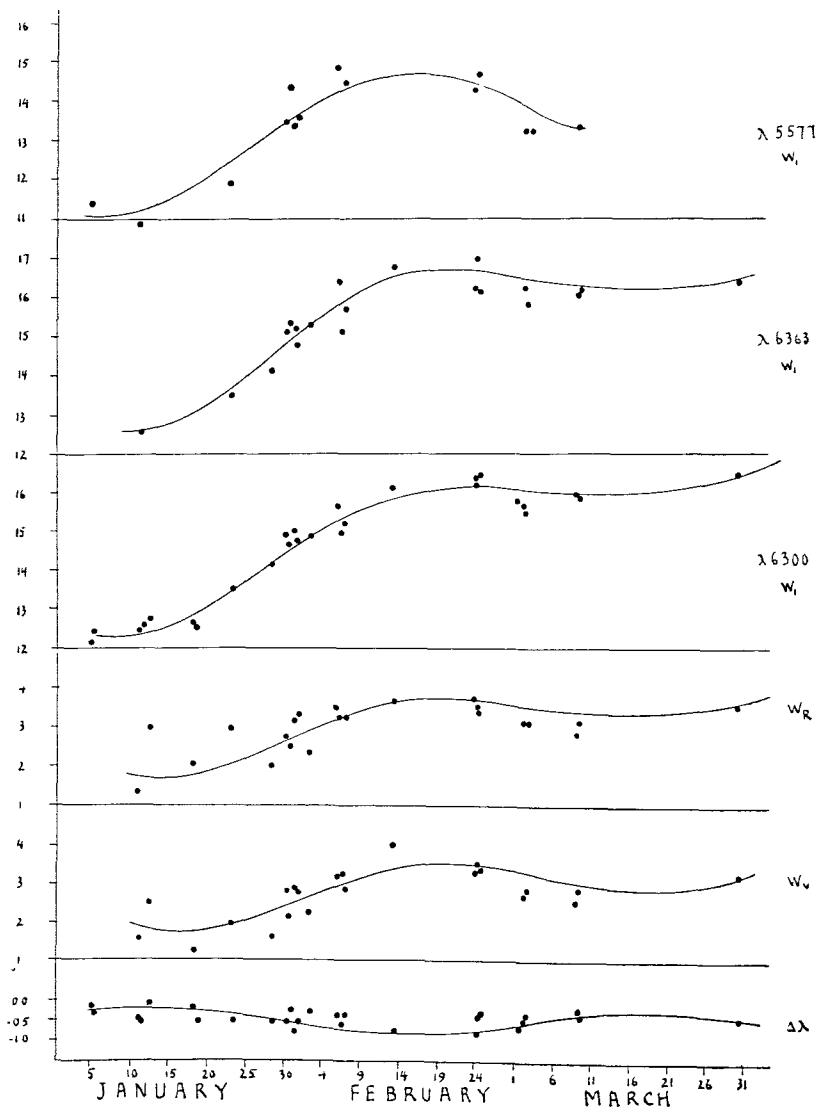
FIG. 1. Variation in width (W_j) of forbidden oxygen lines, of the components (W_R and W_V) of λ6300 and of the displacement (Δλ) of the center of λ6300. Scale in angstroms.

km./sec. derived by the Mount Wilson observers,[1] and 21.4 km./sec. by the Cambridge [2] observers, both from interstellar CaII lines. The component of the solar motion in the direction of the Nova is − 19.1 km./sec.

This agreement of results derived from OI and interstellar CaII shows that the envelope of OI did not move much in reference to the star but was expanding in all directions with a variable acceleration.

The departures of the center for the aurora line are scattered making the average departure − 0.17 Å, or 9.1 km./sec. Since this line was not well defined most of the time the result cannot be considered significant. However, rejecting two very poor measures of January 5 and January 23 we obtain $\Delta\lambda = -0.34$, or $v = 18.3$ km./sec. in good agreement with other values.

When the departures of the center of λ 6300 from its normal position are plotted against the time (Fig. 1) they do not seem to be scattered at random. They remain always negative increasing numerically toward the middle of February and decreasing after that. The curve drawn through the departures so as to satisfy their variation best shows the same period as the curve of the width of the line, but with the phase reversed. Perhaps this point cannot be proved from the available material, but if it is correct, then it would seem that the expansion of the envelope was not altogether symmetrical. It was correlated with the variable acceleration of the expansion. When the acceleration was increasing, the envelope as a whole was moving toward the observer, and vice versa.

The widths (in angstroms) of the emission components of the OI lines not corrected for spreading are given in table 4. It should be remembered that the inner edges of the components were never sharp and measures therefore are not very precise. We have again (Fig. 1) the same kind of a curve with the same period but with the amplitude of about

[1] *Publ. A.S.P.*, **47**, 205, 1935.
[2] *Monthly Notices*, *R.A.S.*, **95**, 573, 1935.

one half the width of the whole line λ 6300. The increase in width of the components proceeded of course less rapidly than in the case of the whole line; in fact it is considerably less than one half of the increase in the width of the whole line. For the period of observation we have for λ 6300 a total increase in width equal to 4.1 A. For both components of this line we have a total increase in width of 1.4 A. Therefore we get only 1.4 A for the increase in width of the whole line if its increase was due solely to the increase in width of the components. The difference 2.7 A in the total increase in width must be attributed to the shifting of the centers of components in both directions from the center of the line. Also since the amplitude of the variation in the width of the whole line is about double that of the components, the periodic variations in the width of line λ 6300 cannot be attributed to the variation in width of its components. The line λ 6363 gives similar but less consistent results.

The relative intensity of the red component is given in table 4 in the columns i_R. The intensity of the violet component was assumed to be 10. It is evident that the components were not of the same intensity. At the beginning of observation the red component was the brighter one, after which its relative intensity was fluctuating. At the end of March the violet component was enormously stronger than the red one. Occasionally, as on January 11, February 13 and March 2, the relative intensities of the components were reversed for the two lines λ 6300 and λ 6363.

The middle of the lines between the two emission components was not altogether structureless. Sometimes, especially at the beginning of the observations a sharp emission line was measured exactly in the middle of the whole wide emission line. This central emission is well marked on microphotograms as late as February 7. All the OI lines showed this effect.

Finally, between January 30 and February 7 wide emission bands were measured on both sides of strong OI-lines. These bands which I call Emission 2 were undoubtedly associated

with the principal emission of OI. Their width is given in table 3. It is seen that their width was very great, about 40 A, and the centers were not greatly displaced in reference to the normal position of the lines. These shoulders are well pronounced on microphotograms of that period. They probably were faintly present during the whole period of observation. No strong emission components as in Emission I were noticed in these bands. They appear to be structureless. The center of the bands shows a velocity of approach (average for all bands) of 19 km./sec.

The strength of the OI forbidden lines in Nova Herculis suggests an abundance of oxygen in its atmosphere. It would be natural to expect the presence of ordinary absorption lines of neutral oxygen during the early stage of the development of the nova when its spectrum was of the A-type. This identification was made by Stratton and Beer [1] on the spectrogram of December 21, 1934 obtained in Cambridge.

THE D-SYSTEM

The first plate of our series, January 5, already shows a highly complicated structure in this region. A variety of interpretations may be adopted. A consistent hypothesis as to the significance of various features may be illustrated by a brief description of plate P489, Jan. 30.464 which shows the structure of the D-lines in its highest development.

There are two sharp absorption lines with $\kappa = 11.7$ which remained the most prominent feature of this part of the spectrum from the beginning to the end of the observation period. The D_1 line is considerably stronger than the D_2 in the ratio of 12 : 10. There is also another pair of absorption lines with $\kappa = 26.3$. These lines are 5.3 A wide, diffuse and by no means structureless. The displacement factor refers to their middle. Their violet side is very sharp giving an impression of strong absorption lines with $\kappa = 29.6$. These absorption features are called, in order of the increase of the displacement factor, Absorption 1, 2, and 3.

[1] Monthly Notices, R.A.S., 95, 432, 1935.

Emission distinct from the continuous spectrum can be seen from Absorption 2 of the D_2 line for some 40 A to the red. It is of highly complicated structure. Absorption 1 is on the violet side of Emission 1. This emission shows a hollow middle and strong flanks as in the OI lines. The red side flank in D_2 is considerably stronger than the violet (10 : 7) as in the FeII multiplet $a^6S - z^6P^0$ on this plate, but not as in the OI lines for which the reverse is true. In D_1 the flanks are of the same intensity. The width of these emission bands is 12.5 and 12.4 A for the D_1 and D_2 lines respectively. Their centers are displaced toward the red by the amount of 0.6 and 0.4 A. A combination of these overlapping emission bands produces an impression of diffuse absorption lines to the red of the first absorption D_1. These absorption lines, however, are nothing but spaces between the strong emission flanks of Emission 1. This is proved by the weakness or absence of these spurious absorption lines when the emission flanks are faint in comparison with the middle of emission bands.

There is also a fainter and more uniform emission (Emission 2) stretching from the second absorption to the red beyond the first emission and thus overlapping it. For this plate the width of the second emission is 34.3 and 34.6 A for D_1 and D_2 respectively, displaced to the red 1.3 and 1.7 A. This emission is very diffuse on the red side and measures cannot be very precise. On this plate the emission flanks of Emission 2 are clearly visible.

The development of the D-structure was not going parallel to the development of other lines; whereas the OI lines were rather consistently developing the flank components in their emission from the beginning to the end of observation, the maximum development of this feature in the D-lines occurred on January 30. Before that date the structure in Emission 1 was not prominent and on January 23 it was almost completely absent. On January 28 it was quite strong and on January 30 it was striking. It was getting less prominent after this date and almost entirely disappeared by March.

The correctness of this interpretation may be seen from the fact that the variation in the width of Emission 1 given (in angstroms) in table 5 (graph, Fig. 2) follows very closely

TABLE 5

D-SYSTEM

Emission 1

Date	Width			Δλ₁		
	D_1	D_2	Mean	D_1	D_2	Mean
Jan. 5.492	13.0	12.4	12.7	+1.0	+0 9	+1.0
Jan. 11.492	12.6	12.4	12.5	+1.1	+1.2	+1.1
Jan. 12.483	12.0	12.7	12.3	+0.7	+0.6	+0.6
Jan. 18.476	12.7	12.2	12.5	+0.5	+0.4	+0.5
Jan. 23.547	13.2	12.9	13.0	+0.8	+0.8	+0.8
Jan. 28.490	11.9	13.3	12.6	+0.3	+0.8	+0.6
Jan. 30.464.	12.5	12.4	12.5	+0.6	+0.4	+0.5
Jan. 30.502	12.4	13.1	12.7	+0.6	+0.9	+0.7
Jan. 31.446	12.5	12.6	12.6	+0 4	+0.7	+0.6
Jan. 31.493	13.1	13.2	13.1	+1.4	+1.2	+1.3
Feb. 6.455	13.8	13.2	13.5	+1.1	+0.8	+0.9
Feb. 6.499	12.6	13.9	13.3	+0.2	+0.6	+0.4
Feb. 7.466	13.8	13.5	13.7	+1.0	+0.7	+0.9
Feb. 13.414.	15.6	15.0	15.3	+1.0	+1.3	+1.2
Feb. 24.397	15.8	14.5	15.1	+1.6	+1.0	+1.3
Feb. 24.477	13.9	14.4	14.2	+0.7	+0.8	+0.8
Mar. 2.413	14.1	14.0	14.0	+0.7	+0.6	+0.7
Mar. 9.376	15.2	14.5	14.9	+1.4	+0.4	+0.9

Emission 2

Date	Width			Δλ₂		
	D_1	D_2	Mean	D_1	D_2	Mean
Jan. 30.464	34.3	34.6	34.5	+1.3	+1.7	+1.5
Jan. 30.502	32.5	32.2	32.4	+1.1	+1.5	+1.3
Feb. 6.455	34.4	34.1	34.3	+1.2	+2.0	+1.6
Feb. 7.466	39.4	37.1	38.2	+3.2	+3.8	+3.5
Feb. 24.477	34.1	33.3	33.7	+1.6	+1.6	+1.6

the width of the OI lines giving a rather flat curve in January, rising sharply at the beginning of February and attaining the maximum at about February 14. The points on the curve are more scattered than in the case of OI which fact should

be attributed to a greater diffuseness of the D emission fea-
tures.   It is seen from Fig. 2 that the maximum width of
Emission 1 did not coincide with the maximum displacement
of Absorption 1.   In other words Emission 1 did not increase
in width uniformly on both sides.   The difference in exposure
and consequent difference in the spreading of Emission 1
cannot explain this departure.   It would rather work in the
opposite direction and shift the maximum in the width of the
emission toward the beginning of the observational period.
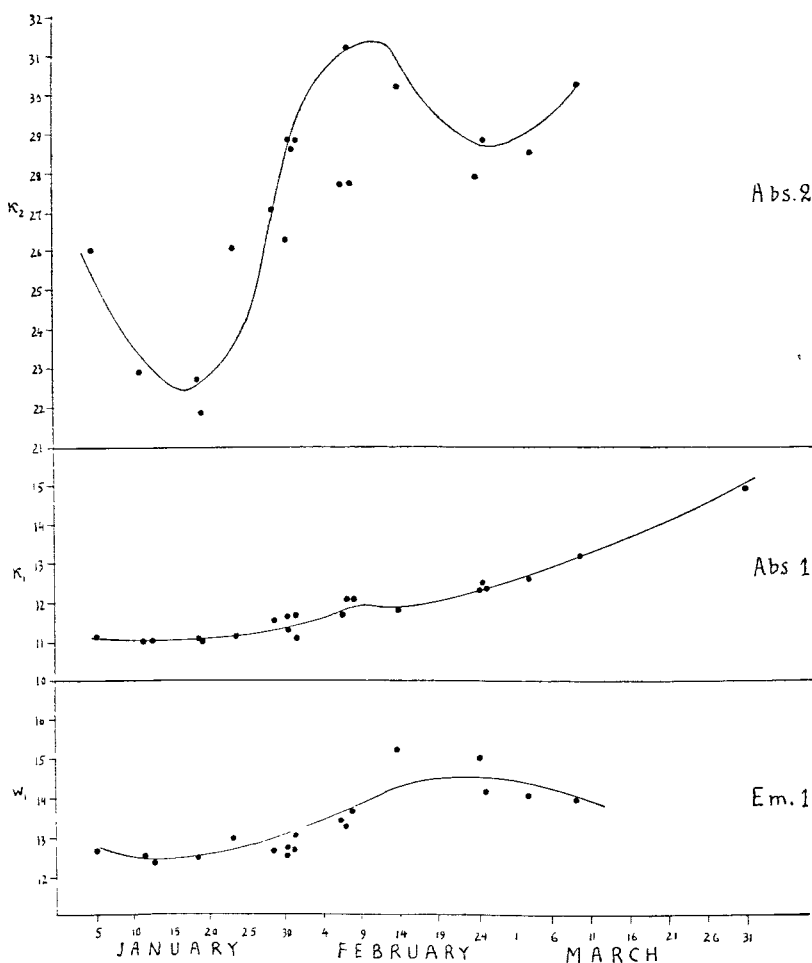
FIG. 2.   Variation in the displacement factor of Absorption 1 and 2 of the sodium
D-lines.   Variation in width of Emission 1 of the sodium lines (in angstroms).

The displacement of the center of Emission 1 (given in table 5 in the columns $\Delta\lambda_1$) was positive, with an average value of 0.82 ± 0.19 A resulting in the velocity of recession of 41.7 ± 9.4 km. sec. This may be contrasted with the behavior of the OI bands which showed the velocity of approach of 21 km. sec.

Emission 2 could be measured on five plates (table 5), during approximately the same interval as Emission 2 of OI, and suspected on many more. It showed the width of about 34 A with the displacement of the center to the red twice as great as in Emission 1. The large value for February 7 seems to be correct, as the red flanks of Emission 2 for this date are well defined.

If we now turn to the absorption features of the D-lines we shall find more precise data. They are given in table 6.

TABLE 6

D-SYSTEM ABSORPTION

Date	κ_1			κ_2			Intensity of D_1	
	D_1	D_2	Mean	D_1	D_2	Mean	1	2
Jan. 5.492	11.01	11.21	11.11	25.4	26.6	26.0	10	5
Jan. 11.492	10.96	10.87	10.92	26.0	21.8	23.9	15	8
Jan. 12.483	11.03	11.04	11.04	—	—	—	15	7
Jan. 18.476	10.80	11.04	10.92	22.8	22.7	22.7	9	3
Jan. 18.506	10.66	11.21	10.86	22.0	21.7	21.9	10	3
Jan. 23.547	11.18	11.10	11.14	26.1	26.3	26.2	8	5
Jan. 28.470	11.55	11.55	11.55	27.0	27.5	27.2	12	5
Jan. 30.464	11.47	11.85	11.66	25.6	27.0	26.3	12	3
Jan. 30.502	11.16	11.37	11.26	29.5	28.3	28.9	10	5
Jan. 31.446	11.72	11.80	11.76	28.5	28.7	28.6	9	5
Jan. 31.493	10.96	10.96	10.96	29.8	27.8	28.8	7	7
Feb. 6.455	11.67	11.57	11.62	29.3	28.2	28.7	10	2
Feb. 6.499	12.30	12.14	12.22	32.1	30.6	31.3	12	5
Feb. 7.466	12.16	12.23	12.20	28.8	28.5	28.6	12	5
Feb. 13.414	11.62	12.05	11.83	30.2	30.1	30.2	12	5
Feb. 24.397	12.45	12.35	12.40	28.4	27.3	27.8	10	7
Feb. 24.446	12.65	12.51	12.58	—	—	—	10	—
Feb. 24.477	12.48	12.40	12.44	29.5	28.3	28.9	9	8
Mar. 2.413	12.80	12.56	12.68	28.6	28.6	28.6	13	3
Mar. 9.376	13.20	13.22	13.21	31.2	29.3	30.3	10	10
Mar. 30.373	14.02	15.60	14.81	—	—	—	10	—

The displacement factors κ_1 and κ_2 are for Absorption 1 and 2 respectively. The intensity of D_1 is given in the last two columns, assuming the intensity of D_2 as equal to 10.

The first absorption D-lines were usually sharp and well defined and measurements were easy and consistent. There seems to be no doubt that on some nights there were rapid fluctuations in the displacement of the D-lines. These fluctuations were especially noticeable on February 6, where both sets of the D-lines give consistent results. The two plates obtained that night are of the same quality.

In general Absorption 1 of the D-lines showed a slow decrease in the displacement factor from the beginning of observations until the middle of January and the subsequent increase toward a maximum at the beginning of February (Fig. 2). After that the displacement factor decreased again but soon began to increase reaching the value of $\kappa = 15$ at the end of March as compared with $\kappa = 11$ at the beginning of January. In other words the velocity of the shell responsible for the absorption of these lines increased from 330 km./sec. to 450 km./sec. in three months.

Absorption 2 shows the same changes in the velocity of approach as Absorption 1 but the amplitude of variation in the former case is much greater. This second set of absorption was not so sharply defined as the first set and measures naturally do not agree so well. Furthermore, Absorption 2 exhibited a rather complex structure. The middle of the absorption was meant to be measured but it is possible that on some fainter spectrograms not the whole absorption line was visible. There seems to be, however, no doubt that the variation of κ for these lines was very great, from $\kappa = 22$ to $\kappa = 31$, that is from 660 km./sec. during the middle of January to 930 km./sec. during the middle of February.

Absorption 3, that is the strongest component of Absorption 2, was prominent on February 7 and 13, besides the already mentioned case of January 30. For February 7 $\kappa_3 = 29.4$ and for February 13 $\kappa_3 = 29.7$. Only D_2 could be measured.

The intensities of the absorption lines deserve special notice. It was difficult to estimate the intensity of the D_2 line of Absorption 1 because in some cases the second absorption was very strong and stretched up to this line. It is seen from table 6 that the D_2 line of Absorption 1 was not always the stronger of the two. Sometimes the D_1 line of Absorption 1 was decidedly stronger than the D_2. In Absorption 2 the D_1 line was always less prominent than D_2, the difference in intensity being sometimes very great. Only on March 9 were these two lines of the same intensity.

Absorption 2, as a whole, was not conspicuous at the beginning of observation. It developed rapidly in the second half of January, and on January 23 it was many times stronger than Absorption 1. After January 23 it rapidly decreased in strength and could barely be recognized on March 9.

The results of the Mount Wilson observers [1] indicate that Absorption 1 of the D-lines before January 5 showed a very rapid increase in the displacement factor, from $\kappa = 9$ on December 23 to $\kappa = 10.7$ on December 25 after which date κ increased very slowly to 11.0 by January 5 in agreement with my results. This shows, however, that the periodicity in the amount of displacement of the D-lines was not evident before January.

The interstellar lines of sodium could not be identified on our spectrograms. They would fall in the region of strong emission flanks of Emission 1 and may therefore be easily concealed.

P. W. Merrill mentions "other components with much greater displacements and an apparently erratic behavior." This refers perhaps to the lines designated in this paper as Absorption 2. No strong absorption to the violet of Absorption 2 is in evidence on our plates. Several faint absorption lines were measured on some plates within 30 angstroms from the D-lines. One of them is undoubtedly the neutral helium line λ 5875.62. On January 28 this line was displaced by 6.68 A, giving $\kappa = 11.4$ in good agreement with the

[1] *Publ. A.S.P.*, 47, 205, 1935.

displacements of the D-lines. But on January 30 a somewhat stronger pair was measured at λ 5866.59 and λ 5861.06. If the first line is the same helium line, then its displacement is − 9.03 Å and κ = 15.4, much greater than for the D-lines. The other line may be SiII λ 5868.40 with the displacement − 7.34 Å and κ = 12.5. On the other hand if this pair belongs to the D-system, then the displacements are − 29.34 Å and − 28.91 Å, with κ = 48.8 and 48.1 which roughly corresponds to Absorption 3 in hydrogen.

<div align="center">HYDROGEN</div>

The development of the hydrogen lines H_α and H_β did not follow the same course. H_α early in January showed the emission core of some 13 Å wide with a strong absorption line on the violet side. Superimposed on this structure was a fainter emission band of some 30 Å width with another absorption band in its violet side. H_α was at that time very similar to the D-lines.

H_β at the beginning also showed a narrow emission core about 10 Å wide with an absorption line on the violet side. There were only traces of the wider emission band.

The emission core (Emission 1) in H_β was of uniform structure except for a week, January 30 to February 6, when it showed traces of a hollow middle like that of the OI lines. This structure never was conspicuous and on February 13 it could be seen no longer. H_α on the other hand showed the first traces of the OI structure at about the same time as H_β, but as the time went on this feature became more and more prominent. In March the core of H_α differed in aspect very little from the OI lines, in contrast with the structureless core of H_β.

The hollow middle of H_α became prominent for the first time on February 2. On this plate the width of the absorption in the core is 4.04 Å with the displacement of the center + 2.50 Å. The width (W) of this absorption and its displacement ($\Delta\lambda$) in angstroms are given in the last two columns of table 7. It is seen that the width of the central absorption

TABLE 7

HYDROGEN ABSORPTION

Date	Absorption 1		Absorption 2		Absorption 3		Central Abs. in H_α	
	H_α	H_β	H_α	H_β	H_α	H_β	W	$\Delta\lambda$
Jan. 5.492	11.0	9.4	—	—	—	—	—	—
Jan. 5.514	10.0	9.8	—	—	—	—	—	—
Jan. 11.492 ...	12.0	13.9	—	—	—	—	—	—
Jan. 11.513	—	13.1	—	—	—	—	—	—
Jan. 12.483	11.3	13.1	24.8	—	—	—	—	+2.78
Jan. 18.476	11.2	12.2	25.5	21.4	—	—	—	—
Jan. 18.506	11.6	12.5	22.2	21.3	—	—	—	—
Jan. 23.547	—	11.7	—	23.3	—	—	—	—
Jan. 28.490	11.9	13.2	32.7	25.7	—	—	—	—
Jan. 30.464.........	12.3	13.1	31.4	28.1	45.7	—	—	—
Jan. 30.502	12.6	—	30.8	—	44.7	—	—	—
Jan. 31.446	13.8	13.1	30.4	28.1	44.9	—	—	—
Jan. 31.493	13.2	13.2	30.5	26.7	43.7	—	—	—
Feb. 2.422...	12.2	13.9	29.6	—	—	—	4.0	+2.5
Feb. 6.455....	—	13.5	—	29.6	—	—	—	—
Feb. 6.499	12.8	—	28.4	—	—	—	2.9	+2.9
Feb. 7.466. . .	13.2	12.6	29.9	29.9	41.8	—	6.5	+1.8
Feb. 13.414. ..	15.0	—	31.0	—	45.7	—	6.5	+1.6
Feb. 13.465........	14.5	—	—	—	—	—	—	—
Feb. 24.397	—	12.0	—	26.1	—	41.5	—	—
Feb. 24.477.......	15.1	—	27.1	—	45.5	—	7.3	+1.3
Mar. 1.441.	16.2	—	28.6	—	—	—	8.9	0.0
Mar. 2.413..	17.7	12.6	29.4	28.3	47.5	—	7.9	−0.6
Mar. 2.469	16.0	—	28.6	—	42.8	—	8.7	−0.6
Mar. 9.376	16.2	—	28.6	—	—	—	—	—
Mar. 9.455...	14.9	—	29.6	—	43.0	—	8.3	+0.6
Mar. 30.373..........	(16.4)	—	(28.9)	—	(45.6)	—	9.1	(−2.2)

in H_α oscillated, generally increasing with the time, and becoming more symmetrical in reference to the normal position of H_α. On the plate of January 12 a very narrow absorption line was measured in the emission core of H_α. The connection of this absorption line with the subsequent development of the absorption core in H_α is not clear.

The displacement factors for various absorptions of H_α and H_β are given in table 7. The diagram (Fig. 3) shows considerable scattering of values for both lines. This may be due either to actual variations in the radial velocity or else to

the variation in the structure of absorption lines. All the absorption components were complex, apparently each consisting of a number of absorption lines. Of course on weaker spectrograms the micrometer wire would be set on the strongest component instead of on the middle of the line.
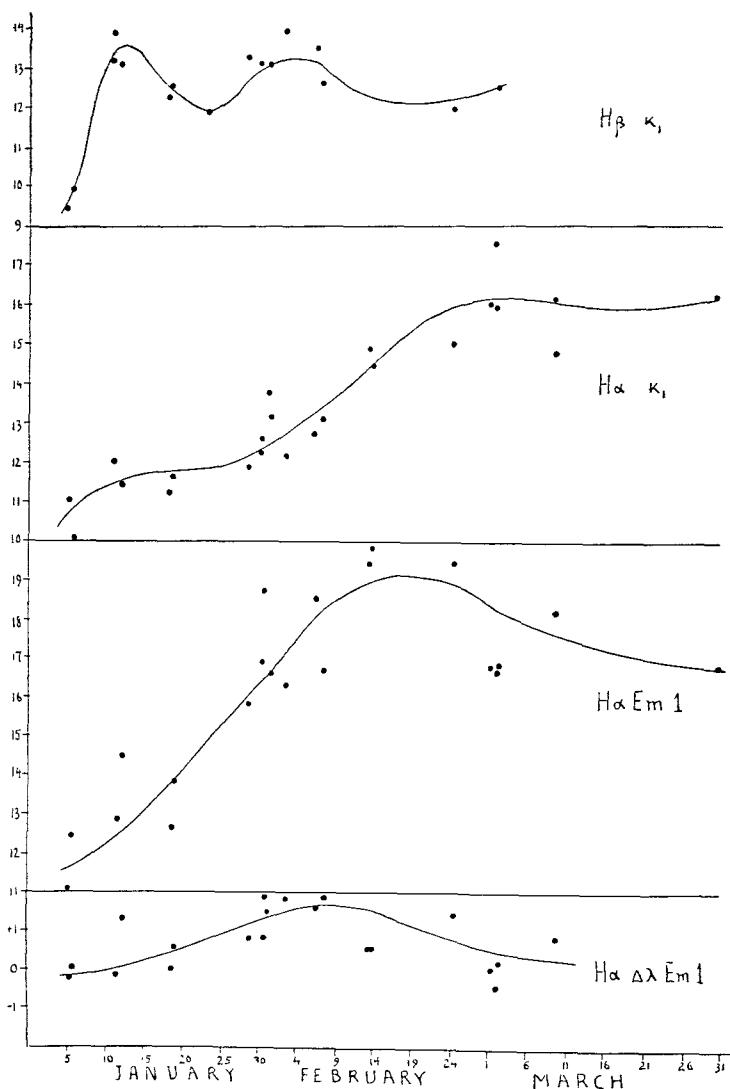
FIG. 3. Variation in the displacement of the center of Emission 1 of H_α (in angstroms) and of the width of Emission 1 of H_α. Displacement factors for Absorption 1 of H_α and H_β.

The curves for the displacement factors of the hydrogen lines differ greatly from the curve of the D-lines. In fact the only common feature is the gradual increase in the displacement factors from the beginning of January to the end of March.

The maximum displacement of Absorption 1 in H_α occurred early in March. H_β appears to have a double maximum, one at about January 10 and another in the beginning of February. There are traces of this double maximum in H_α also.

Absorptions 2 and 3 appear to be quite irregular. The data for the last line in table 7 were obtained by extrapolation and are less reliable.

TABLE 8

WIDTH OF HYDROGEN EMISSION

Date	Emission 1		Emission 2		Emission 3		Emission 4
	H_α	H_β	H_α	H_β	H_α	H_β	H_α
Jan. 5.492	11.0	10.5	31.5	—	—	—	—
Jan. 5.514	12.4	9.0	30.5	—	—	—	—
Jan. 11.492	12.8	10.2	33.0	24.4	—	—	—
Jan. 11.513	—	11.5	—	—	—	—	—
Jan. 12.483	14.5	13.2	29.9	—	—	—	—
Jan. 18.476	12.5	12.0	31.2	—	—	—	—
Jan. 18.506	13.8	14.1	30.1	—	—	—	—
Jan. 23.547	—	12.0	—	—	—	—	—
Jan. 28.490	15.8	13.3	31.9	27.1	43.9	—	—
Jan. 30.464	17.9	12.4	36.9	27.6	52.4	42.2	—
Jan. 30.502	18.7	—	37.1	—	54.5	—	—
Jan. 31.446	16.6	12.7	35.8	28.1	53.8	47.6	—
Jan. 31.493	—	12.4	34.8	27.8	51.5	—	—
Feb. 2.422	16.3	15.9	32.9	—	53.0	—	—
Feb. 6.455	—	13.9	—	28.3	—	—	—
Feb. 6.499	18.6	—	38.0	—	—	—	—
Feb. 7.466	16.7	14.1	33.8	28.3	47.2	—	—
Feb. 13.414	19.5	—	38.7	—	58.3	—	—
Feb. 13.465	19.9	—	—	—	—	—	—
Feb. 24.397	—	15.8	—	30.6	—	—	—
Feb. 24.477	19.6	—	33.1	—	53.6	—	—
Mar. 1.441	16.9	—	39.3	—	57.5	—	—
Mar. 2.413	16.8	12.7	36.3	28.3	58.5	—	76.9
Mar. 2.469	16.9	—	35.7	—	52.2	—	73.3
Mar. 9.455	18.4	—	35.9	—	52.6	—	—
Mar. 30.373	17.0	—	34.0	—	54.5	—	—

The width (in angstroms) of various emission features in the hydrogen lines is given in table 8. Early in March four superimposed on each other emissions could be measured. Emission 4 shows that the maximum relative velocity of the expanding shells was of the order of 3400 km./sec.

Figure 3 represents the width of Emission 1 of H_α. The maximum occurred in the middle of February as in other emission features of the nova. Emission 2 of H_α shows substantially the same picture.

The displacements (in angstroms) of the centers of the

TABLE 9

HYDROGEN EMISSION

Displacement of Center

Date	Emission 1		Emission 2		Emission 3		Emission 4
	H_α	H_β	H_α	H_β	H_α	H_β	H_α
Jan. 5.492 ...	−0.3	+1.2	−0.1	—	—	—	—
Jan. 5.514..	0.0	+0.8	0.0	—	—	—	—
Jan. 11.492... .	−0.2	−0.2	−0 5	−1.5	—	—	—
Jan. 11.513 ..	—	+0.6	—	—	—	—	—
Jan. 12.483.....	+1.3	+0.4	+1.3	—	—	—	—
Jan. 18.476 ...	−0.1	+1.0	+1.5	+1.2	—	—	—
Jan. 18.506 ..	+0 5	+0.1	+1.4	—	—	—	—
Jan. 23.547.....	—	−0.6	—	—	—	—	—
Jan. 28.490. ...	+0.8	+2.6	+1.7	+2 8	+2.3	—	—
Jan. 30.464 ...	+0.9	+0.9	−0.6	+2.7	−1.4	+1.2	—
Jan. 30.502....	+1.9	—	+0.1	—	−0.5	—	—
Jan. 31.446. . .	+1.4	+1.1	−0.2	+2 0	−0.6	—	—
Jan. 31.493. .	—	+1.3	−0 6	+2.8	−0.7	—	—
Feb. 2.422.. .	+1.8	+3.3	+2.3	—	+3.1	—	—
Feb. 6.455.....	—	+1 5	—	+1.9	—	—	—
Feb. 6.499 ...	+1.5	—	+1.0	—	—	—	—
Feb. 7.466. .	+1.7	+2.5	−0.1	+1.6	−1.3	—	—
Feb. 13.414 ...	+0 4	—	+0.9	—	+1.5	—	—
Feb. 13.465... .	+0.4	—	—	—	—	—	—
Feb. 24.397 ...	—	+3.5	—	+4.4	—	—	—
Feb. 24.477 . .	+1.3	—	+1.2	—	−1.0	—	—
Mar. 1.441 ...	+0.1	—	−0.5	—	+0.1	—	—
Mar. 2.413 ...	−0.6	+2 6	+0.8	+2.4	−0.3	—	−0.5
Mar. 2.469....	+0.3	—	+1.4	—	+0.6	—	−0.7
Mar. 9.455.. ..	+0.9	—	+0.5	—	+0.2	—	—
Average... .	+0.70	+1.33	+0.58	+1.83	+0.15		
v km./sec. ..	+32	+82	+27	+112	+7		

emission bands from their normal positions are given in table 9.

The averages of the displacements give positive values throughout, but the resulting velocity varies from 7 to 112 km./sec. The average values for Emissions 1 and 2 are 30 km./sec. for H_α and 97 km./sec. for H_β. The general average is 52 km./sec.

Perhaps the average value does not mean much in this case. Plotting the values of the residuals against time (Fig. 3) a very definite curve is obtained. This curve follows the variations of the width of the emission bands with a distinct maximum near the middle of February. Emission 1 of H_α gives the most consistent results probably because it was best defined. There is a striking difference between the curve of the departures for H_α and the similar curve for the OI λ 6300 (Fig. 1). Except for the fact that the values of $\Delta\lambda$ for hydrogen are somewhat larger than for oxygen, the two curves are the reverse of each other. This variation can be seen well also in Emission 1 of H_β, and in Emission 2 of H_α. Other emissions were not sufficiently well defined to show this effect definitely.

It is of interest to note that the emission D-lines do not show any systematic variation in the displacement of their centers.

The first two weeks in January the emission bands in H_α and H_β were stronger on the violet side. Later, at about January 18, the red sides became much stronger. Generally speaking the red edges of the emission H_α were indistinct and merged into each other. In H_β on the other hand beginning with January 30 the red edges were almost as well defined as the violet edges. The red edges were undoubtedly measured by some observers as independent absorption lines. Certain lines of FeII, especially in the multiplet $a^6S - z^6P^0$, showed the same effect.

IONIZED IRON

The lines of ionized iron were conspicuous during the first two months of observation. On the plate of January

5.492 all the lines of FeII given by Miss Moore [1] between H_α and H_β could be identified. The fainter ones soon became indistinct with the increase in the strength of the continuous spectrum.

The FeII lines on January 5 present substantially the same appearance as H_β, described above. The results of measurement are given in table 10.

TABLE 10

IONIZED IRON

January 5.492

J	λ	Lab. i	Emission in Nova			κ	Blend
			Width	$\Delta\lambda$	i		
$a^6S - z^6P^0$							
$2\frac{1}{2}-1\frac{1}{2}$	4923.93	20	9.7	$+2.2$	4	7.76	
$2\frac{1}{2}-2\frac{1}{2}$	5018.45	20	11.0	$+2.2$	6	8.95	
$2\frac{1}{2}-3\frac{1}{2}$	5169.05	20	12.0	$+2.1$	10	9.55	
					Mean	8.75	
$a^4G - z^4F^0$							
$2\frac{1}{2}-1\frac{1}{2}$	5197.58	4	10.1	$+0.7$	4	11.52	
$3\frac{1}{2}-2\frac{1}{2}$	5234.63	4	10.9	$+1.1$	4	10.01	
$4\frac{1}{2}-3\frac{1}{2}$	5276.00	5	—	—	6	10.86	
$5\frac{1}{2}-4\frac{1}{2}$	5316.62	8	9.6	$+2.3$	8	10.19	
$3\frac{1}{2}-3\frac{1}{2}$	5325.56	0	—	—	2	9.31	
$2\frac{1}{2}-3\frac{1}{2}$	5346.55	p	—	—	1	11.24	
$4\frac{1}{2}-4\frac{1}{2}$	5425.26	p	—	—	1	14.35	
					Mean	11.07	
$a^6S - z^6F^0$							
$2\frac{1}{2}-2\frac{1}{2}$	5256.93	p	—	—	1	14.04	
$2\frac{1}{2}-3\frac{1}{2}$	5284.11	p	—	—	1	10.68	CaII 5285.34
					Mean	12.36	

[1] A Multiplet Table of Astrophysical Interest, Princeton, 1933.

TABLE 10—*Continued*

$a^4G - z^4D^0$

$2\frac{1}{2}-1\frac{1}{2}$	5264.81	I	—	—	I	13.12	
$3\frac{1}{2}-2\frac{1}{2}$	5316.78	p	—	—	—	—	FeII 5316.62
$2\frac{1}{2}-2\frac{1}{2}$	5337.73	p	8.9	+0.4	I	9.67	CrII 5337.76
$4\frac{1}{2}-3\frac{1}{2}$	5362.87	p	13.1	+1.7	2	11.15	
$3\frac{1}{2}-3\frac{1}{2}$	5414.08	p	—	—	I	9.45	
$2\frac{1}{2}-3\frac{1}{2}$	5435.70	?	—	—	I	13.76	OI 5436.83
					Mean	11.43	

$b^4D - z^4P^0$

$1\frac{1}{2}- \frac{1}{2}$	6147.75	o	10.4	−0.4	6	11.75	
$\frac{1}{2}- \frac{1}{2}$	6149.26	oo				11.94	
$1\frac{1}{2}-1\frac{1}{2}$	6238.40	o	6.0	+3.8	3	12.48	
$\frac{1}{2}-1\frac{1}{2}$	6239.96	p				12.48	NII 6242.52
$2\frac{1}{2}-1\frac{1}{2}$	6247.57	I	9.9	−0.6	10	9.93	
$1\frac{1}{2}-2\frac{1}{2}$	6407.31	p	9.3	−0.9	3	10.72	
$2\frac{1}{2}-2\frac{1}{2}$	6416.94	o	11.5	+0.6	3	10.73	OI 6453–56
$3\frac{1}{2}-2\frac{1}{2}$	6456.40	3	13.3	+1.0	6	11.50	
					Mean	11.44	

$a^6S - z^6D^0$

$2\frac{1}{2}-1\frac{1}{2}$	6369.48	p	—	—	I	11.20	SiII 6371.36
$2\frac{1}{2}-2\frac{1}{2}$	6432.69	p	11.4	−0.2	3	12.04	
$2\frac{1}{2}-3\frac{1}{2}$	6516.09	oo	12.6	+0.1	2	12.45	
					Mean	11.90	

The displacements of the centers of emission core ($\Delta\lambda$) are preponderantly positive as in all emission lines of this Nova, except OI. The displacement factors vary greatly even within the same multiplet. This is not surprising in view of the difference in the behavior of H_α and H_β. Generally speaking the displacement factors increase with the increase of the wave-length.

In the first column of table 10 the inner quantum numbers are given. The letter p in the column for laboratory intensities means that the line was predicted.

The intensities of the emission lines of FeII in the star differ considerably from the laboratory data. Especially

noteworthy is the difference in intensity in the first multiplet, the lines of which in the laboratory are of equal intensity. The prominence of the fainter lines in the star is also remarkable. The two recently published papers describing the spectrum of the nova on January 3 [1] and January 4 [2] do not mention some of these lines. The last column of table 10 gives possible blends with other lines.

The displacement factors for the multiplets $a^6S - z^6P^0$, $a^4G - z^4P^0$ and $b^4D - z^4P^0$ are given in tables 11, 12 and 13.

TABLE 11

IONIZED IRON

Displacement Factors

$a^6S - z^6P^0$

Date	Absorption 1				Absorption 2			
	λ4923	λ5018	λ5169	Mean	λ4923	λ5018	λ5169	Mean
Jan. 5.492	7.8	9.0	9.6	8.8	—	—	—	—
Jan. 11.492	12.5	13.0	11.8	12.4	—	—	—	—
Jan. 11.513	13.2	11.2	10.5	11.6	—	—	—	—
Jan. 12.483	12.6	12.5	11.5	12.2	—	—	—	—
Jan. 18.476	11.2	11.6	11.0	11.3	25.0	24.1	22.3	24.1
Jan. 23.547	12.2	11.2	11.0	11.5	26.2	25.5	24.4	25.4
Jan. 28.490	13.6	12.4	12.4	12.8	26.2	25.7	25.6	25.8
Jan. 30.464	13.6	12.4	12.2	12.7	29.3	23.7	26.5	26.5
Jan. 31.446	15.0	12.7	13.1	13.6	—	30.8	28.5	29.3
Feb. 6.455	13.1	11.9	13.1	12.6	28.5	27.5	28.1	28.0
Feb. 7.466	13.2	12.4	12.3	12.6	27.4	27.2	29.1	27.9
Feb. 24.397.	15.9	15.3	14.5	15.9	25.7	26.2	24.5	25.5
Mar. 2.413	16.9	14.7	15.8	15.8	—	26.1	—	26.1
Mar. 9.376	18.7	15.1	15.2	16.3	—	—	—	—

The values of the displacement factor are scattered especially for the last two multiplets. The most likely explanation of this scattering is the same as in the case of the hydrogen lines, namely the complex structure of the absorption lines. Other multiplets have been measured only on a few plates. They show approximately the same displacement factors as the ones given above for the same data.

[1] Grotrian and Rambauske, *Zeitschrift f. Astrophysik*, **10**, 209, 1935.
[2] Beer, Monthly Notices, *R.A.S.*, **95**, 538, 1935.

TABLE 12

IONIZED IRON

Displacement Factors

$a^4G - z^4F^0$

Date	Absorption 1					Absorption 2				
	λ5197	λ5234	λ5276	λ5316	Mean	λ5197	λ5234	λ5276	λ5316	Mean
Jan. 5.492	11.5	10.0	10.9	10.2	10.7	—	—	—	—	—
Jan. 11.492	12.4	13.3	12.3	10.2	12.0	—	—	—	—	—
Jan. 11.513	—	—	—	11.0	11.0	—	—	—	—	—
Jan. 18.476	11.7	11.1	11.5	10.7	11.3	23.6	24.5	21.3	22.2	22.9
Jan. 23.547	11.5	9.8	12 1	11.3	11.2	22.1	23.5	26.0	25.2	24.2
Jan. 28.490	—	—	13 6	—	13.6	—	—	—	28.1	28.1
Jan. 30.464	15.4	14.5	12.1	13.7	13.9	27.7	26.6	24.9	25.6	26.2
Jan. 31.446	13.1	14.8	16.7	15.3	15.0	28.6	24.1	25.3	24.3	25.6
Feb. 6.455	13.9	15.4	12.1	11.0	13.1	27.6	25.9	23.9	25.1	25.6
Feb. 24.397	—	—	15.3	13.9	14.6	—	—	26.7	24.8	25.8

TABLE 13

IONIZED IRON

Displacement Factors

$b^4D - z^4P^0$

Date	Absorption 1					
	λ6147	λ6238	λ6247	λ6416	λ6456	Mean
Jan. 5.492	11.8	12.5	9.9	10.7	11.5	11.3
Jan. 11.492	—	10.9	10.7	11.7	10.7	11.0
Jan. 11.513	—	—	10.3	—	9.8	10.0
Jan. 12.483	—	—	—	—	10.7	10.7
Jan. 18.476	—	—	11.2	—	—	11.2
Jan. 23.547	—	11.1	—	—	—	11.1
Jan. 28.490	—	12.2	9.6	—	—	10.9
Jan. 30.464	13.7	15.5	14.5	—	15.3	14.7
Jan. 31.446	13.7	14.3	13.1	—	14.5	13.9
	Absorption 2					
Jan. 18.476	—	—	22.2	19.8	18.3	20.1

The diagram (Fig. 4) shows in the multiplet $a^6S - z^6P^0$ a very rapid increase in the displacement factor early in January, not shared by the other two multiplets. The curve of Absorption 1 of $a^6S - z^6P^0$ is quite analogous to the curve of
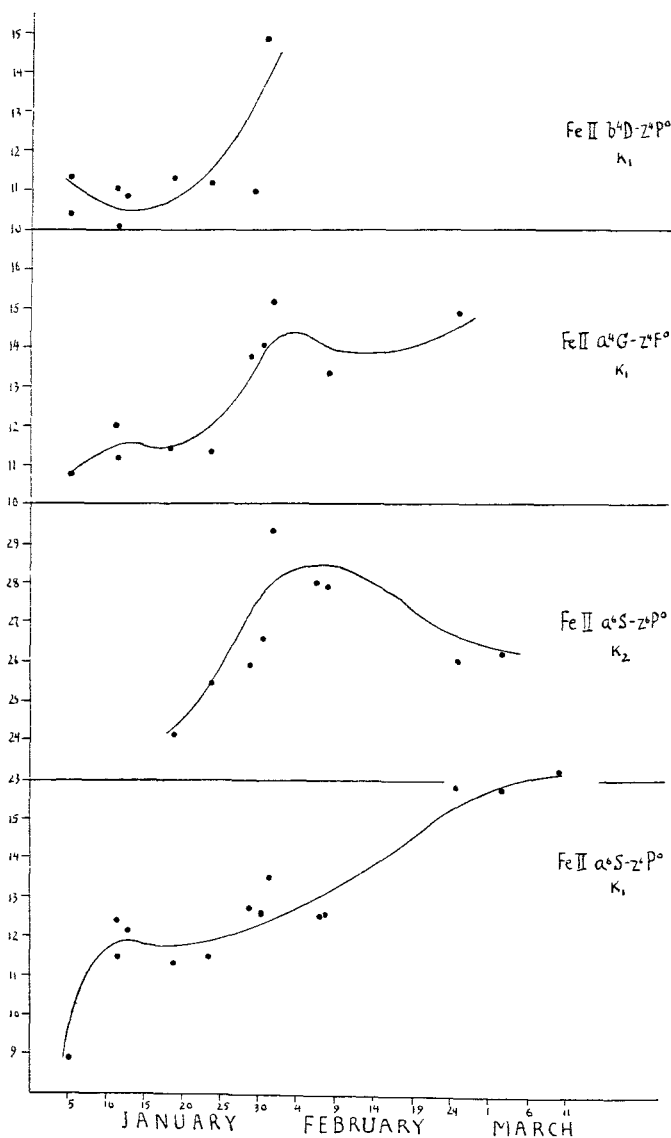
FIG. 4.   Variation in the displacement factors of the ionized iron multiplets.

the hydrogen lines, whereas $a^4G - z^4P^0$ and $b^4D - z^4P^0$ behaved more like the sodium D-lines.

The displacements of the center of Emission I for the three strongest multiplets are given (in angstroms) in tables 14, 15 and 16.

TABLE 14

Ionized Iron

$a^6S - z^6P^0$

Date	Displacement of Center of Emission 1		
	λ4923	λ5018	λ5169
Jan. 5.492............	+2.2	+2.2	+2.1
Jan. 11.492...........	+0.8	+0.7	+1.1
Jan. 11.513...........	+1.2	+0.7	+1.5
Jan. 12.483	+2.9	−0.5	+1.6
Jan. 18.476	+0.8	+0.6	+0.7
Jan. 23.547	+0.9	+1.5	+0.0
Jan. 28.490........ ..	+1.1	+0.5	+0.5
Jan. 30 464.....	+0.0	−0.1	+1.1
Jan. 31.446	−1.0	0.0	+0.8
Feb. 6.455.....	−0.6	+0.6	+0.7
Feb. 7.466...... ..	+1.5	+0.1	+1.0
Feb. 24.397...........	+1.2	+1.1	+1.3
Mar. 2.413...........	+0.5	+0.3	−1.3
Average..............	+0.88	+0.53	+0.85
v km./sec.............	+54	+32	+49 Average v = + 45 km./sec.

TABLE 15

IONIZED IRON

$a^4G - z^4F^0$

Date	Displacement of Center of Emission 1			
	λ5197	λ5234	λ5276	λ5316
Jan. 5.492.......	+0.7	+1.1	—	+2.3
Jan. 11.492.......	+0.9	0.0	+0.6	+1.1
Jan. 11.513.......	—	—	—	+1.4
Jan. 18.476.......	−2.0	−0.5	−0.3	+0.5
Jan. 23.547.......	+0.6	—	—	—
Jan. 28.490......	—	—	+1.0	—
Jan. 30.464.	+0.5	−0.1	+0.5	−0.7
Jan. 31.446.......	+0.4	+0.1	−0.9	−0.2
Feb. 6.455.......	−0.5	−0.5	+0.1	+1.0
Feb. 24.397.......	—	—	+0.5	+1.5
Average..........	+0.11	+0.02	+0.21	+0.86
v km./sec.........	+6	+1	+12	+49 Average v = + 17 km./sec.

TABLE 16

IONIZED IRON

$b^4D - z^4P^0$

Date	Displacement of Center of Emission 1		
	$\lambda6247$	$\lambda6416$	$\lambda6456$
Jan. 5.492	−0.6	+0.6	+1.0
Jan. 11.492............	+0.7	−0.5	+0.5
Jan. 11.513............	+0.1	—	+0.9
Jan. 18.476	−0.1	—	−0.1
Jan. 30.547............	−0.5	—	−1.0
Jan. 31.446...........	+0.5	—	−0.2
Feb. 6.455	+0.2	—	—
Average..............	+0.04	+0.05	+0.18
v km./sec.	+2	+2	+8 Average $v = +$ 4 km./sec.

It is seen that the values of the radial velocity of recession for the multiplet $a^6S - z^6P^0$ are in approximate agreement giving an average value of + 45 km./sec. The same may be said of the multiplet $b^4D - z^4P^0$ but the average velocity in this case is very small, + 4 km./sec. In the multiplet $a^4G - z^4F^0$ the first three lines give an average velocity of + 6 km./sec. or approximately the same as for the multiplet $b^4D - z^4P^0$ while line λ 5316 indicates an entirely different velocity of 49 km./sec. agreeing with the multiplet $a^6S - z^6P^0$. It seems that the multiplet $a^4G - z^4F^0$ did not behave as a unit. The average velocity for the three multiplets is 22 km./sec.

The difference in the behavior of lines of ionized iron belonging to the same multiplet was sometimes striking. On the plate of February 6, for instance, Emission 2 is clearly seen in all the lines of the multiplet $a^6S - z^6P^0$, but the relative intensity of the violet and red wings of this emission is not the same. For λ 4923, the ratio of intensities of the wings $v : r = 5 : 10$, in λ 5018 $v : r = 10 : 10$, and in λ 5169 it is 12 : 10. H_3 on this plate shows the ratio is 1 : 10. On January 30 the emission cores in this multiplet showed a structure analogous to that of the OI lines. The emission

flanks in the core were prominent, but the red component in λ 4923 was much stronger in reference to the violet than in λ 5018 and 5169.

Absorption 2 appeared distinctly for the first time on January 18. It was of great width (5–6 A) and ill defined in contrast with the sharp lines of Absorption 1. Later, however, the difference in the aspect of these two lines became smaller. Both lines were broad and diffuse by the end of February.

The core of the FeII lines was well defined on the red side. Sometimes, as on January 30, there was on the red side an absorption line equal in strength to the absorption line in the violet side of the core. This effect could be seen in most FeII lines, but was most striking in the multiplet $a^6S - z^6P^0$.

OTHER RADIATIONS

The spectrum of Nova Herculis in the visual region may be said to consist almost exclusively of the emission and absorption lines of H, O, Na and FeII. All other radiations were very faint and inconspicuous in comparison with those named above.

Faint absorption and emission lines mostly of TiII, CrII, ScII, CII and NII have been measured on several plates taken in January and February. Some of these lines are mentioned by Beer in his paper [1] as occurring in emission. Their precise identification is not a simple matter in view of the difference in the displacement factors. There are a few lines, however, which are of especial interest. A brief discussion of them is given below.

On the plate of January 30.464 there is a broad emission line having the same structure as the OI lines, that is two strong emission components with the center fainter than the flanks. Its width is 13.4 A and its center is at λ 5991.1. There are fainter flanks extending from λ 5976.0 to λ 6008.8 thus giving 32.8 A for the width of the whole band. On January 31 the band was much fainter but the peculiar struc-

[1] Beer, Monthly Notices, R.A.S., **95**, 538, 1935.

ture of the OI could be clearly seen.   The wave-length of its center was 5991.7, and the width of the central part was 15.6 A.   No absorption could be seen on either date.

Beer gives a line of unknown origin at λ 5191.4 strong in the sun but weak in sunspots.   It is present in α Persei, and was observed in Nova Pictoris.   According to Beer the behavior of this line in Nova Herculis was irregular.

On the plate of January 5.492 an emission line of 7.8 A width with the center at λ 6444.2 was measured.   It is accompanied by an absorption line at λ 6439.6.   This line is not mentioned by Beer.   Perhaps this is the line of unknown origin at λ 6442.9 observed by Dunham [1] in α Persei.

Wide absorption bands of considerable intensity not associated with emission have been measured on several spectrograms.   Perhaps they are blends of absorption lines.   A comparison with the spectrum of α Persei does not give reliable identification.   The most intense bands were found at $\lambda\lambda$ 6329–41, 6354–66 (January 5), and at $\lambda\lambda$ 5213–17, 5248–59, 6137–42, 6328–35 (January 18).

CONTINUOUS SPECTRUM

Tracings obtained with the Moll microphotometer of Ohio State University indicate great variations in the strength of the continuous spectrum in the red part of the spectrum.   Before January 18 and after March 1 there was practically no slope to the line of the continuous spectrum on the tracings. On January 18, however, the maximum intensity of the continuous spectrum between H_α and the D-lines seemed to be in the neighborhood of λ 6300.   On January 28 the maximum intensity shifted to λ 6500, and on January 30 it was in the region H_α.   On February 7 the maximum shifted again to λ 6300, and by March there was no well expressed maximum.   Such variations in the distribution of intensity of the continuous spectrum should affect the color temperature of the Nova, producing the effect of an irregular variation in temperature.   Indeed the values of color temperature of the

[1] *Princeton Observatory Contributions*, No. 9, 1929.

star derived by Petrie [2] vary from 7,800° K to 13,000° K giving an average of 10,500° K on the Greenwich system.

GENERAL REMARKS

Novæ show a great diversity of phenomena implying an extreme complexity of physical processes involved. It is of course premature to evolve a complicated theory based on fragmentary data. Still there are a few salient points which may belong only to the time of the maximum brightness of the Nova and which indicate a definite period in the development of this star.

The curves of the variation of the displacement factors and width of the emission lines with time (Figs. 1, 2, 3, and 4) differ somewhat from each other, but they all have one feature in common. They all show a wave superimposed on the straight line of the increase in the displacement or in width. It seems as if a periodic process of some kind was going on in the Nova. In view of the subsequent discovery of the double nature of the star it may be permissible to think that the Nova had two components even at its maximum brightness. The shape of the emission lines, first of OI and later of FeII and H_α, would alone indicate the presence of another body or else of two symmetrical jets issuing from the star. The period of variation of spectral features, some three months, need not repeat itself later in the history of the Nova. The fission may have occurred early in January after which time the components have been receding from each other.

If the variation in the width and displacement of emission lines is due to the orbital motion of the components, the general increase of both width and displacement must be accounted for by the accelerated expansion of the envelopes. Here we get into a difficulty, for the displacement of the center of emission lines was not the same for all spectral lines. Recapitulating the data given in appropriate places we have:

[2] *Ap. J* , **81**, 482, 1935.

TABLE 17

RADIAL VELOCITY FROM EMISSION LINES

Element	Velocity
Oxygen.....	. −21 km./sec.
Hydrogen H_α (Emiss. 1 and 2)... .. ..+30 km./sec.	
Hydrogen H_β (Emiss. 1 and 2)...	..+97 km /sec.
Hydrogen (mean)	...+52 km./sec.
Sodium.	.. .. ..+42 km./sec.
Ionized Iron (mean)	..+22 km./sec.

Only oxygen gives a velocity of approach equal to that obtained from the interstellar calcium lines.   In other words the oxygen shell was very nearly at rest in reference to the star.   All other elements show widely different but always positive velocities of recession.   We have to suppose that only the oxygen envelope was common to both components of the nova, whereas the other envelopes belonged to the component which was receding from us during the period of observation.   But it is precisely the structure of the oxygen lines that gives the best indication as to the existence of two components from the very beginning of observation.   This contradiction in terms is perhaps a warning to stop theorizing until more data are available.

The irregular behavior of spectral lines seems to be well established.   This is particularly true of sodium and oxygen because these two elements give the best defined spectral lines.   The deviations from the mean curve are far too great to be attributed to accidental errors.   This is probably an actual variation in the velocity of the expansion of the envelopes.   This fact is not surprising.   Nova Herculis was remarkable for its large and irregular variations in brightness. Whether there was any period in these variations remains to be seen.   P. M. Ryves [1] reports evidence of periods of four and six days.

The general trend of the curves of displacement factors and of the width of spectral lines seems to be parallel to the light curve of the nova.   With the decrease in brightness the displacement factors increased and the emission lines became

[1] Monthly Notices, R.A.S., **95**, 535, 1935.
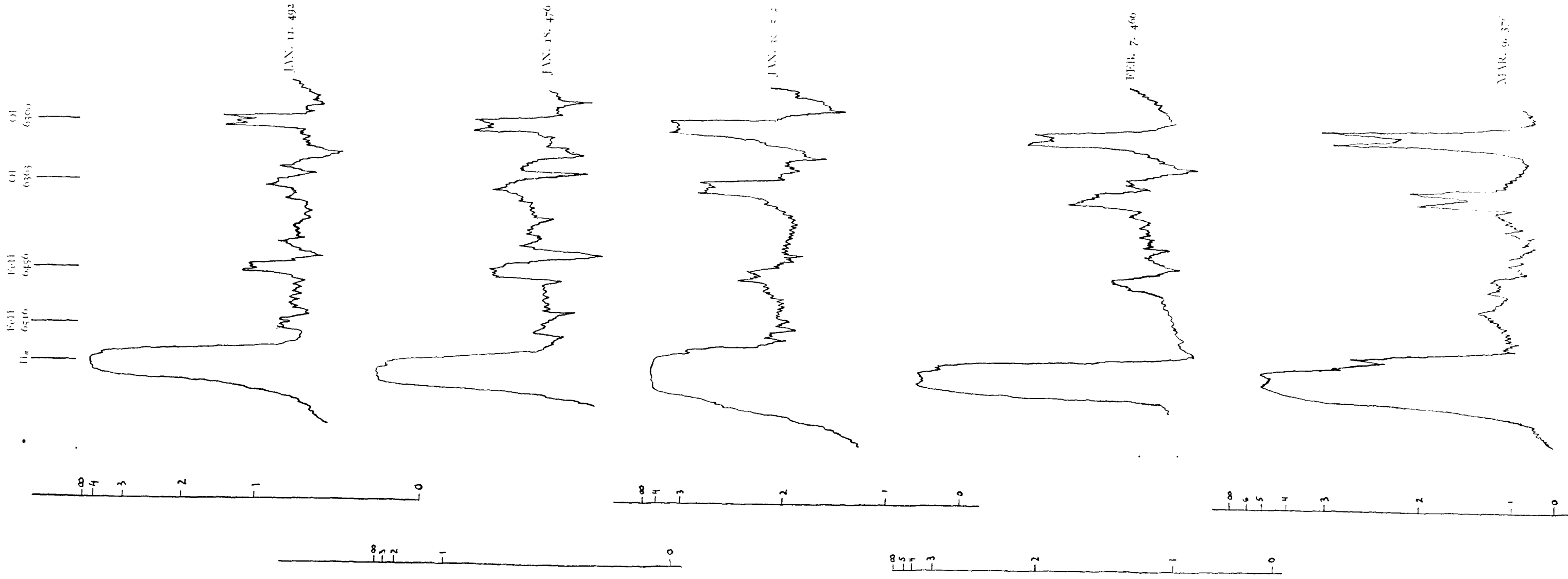
FIG. 5.   Microphotometer tracings of the spectrum between Hα and λ6392.

wider.   The outstanding peculiarity of the curve of the displacement factors of H_3 and of the multiplet FeII a^6S — z^6P^0 is the rapid rise between January 5 and January 15. H_α shows the same effect but not so conspicuously.   The Mount Wilson results show a similar sharp increase in the displacement factors of the D-lines of sodium between December 22 and December 26.   Perhaps we have to deal here with a lag in the development of the absorption lines of hydrogen and ionized iron as compared with those of sodium.

Figure 5 gives microphotometer tracings of a few spectrograms on selected dates between H_α and the oxygen line λ 6300.   They were copied from original records.   The scales on the left side show the density calibration obtained with an Eastman filter K_2.   The steps are 0.7 stellar magnitude each. Step O means clear film, and step ∞ complete opacity.

The gradual development of the central absorption in H_α can be seen well.   On March 9 the shape of the central portion of H_α was approaching that of the oxygen lines, although the absorption was not so deep.   Other interesting features are the gradual disappearance toward March of the central emission in λ 6300, the increase in strength of the emission flanks in the oxygen lines as compared with the center, and the great strength of the FeII lines early in January.

The same picture is clear in Plate I which gives the portion of the spectrum between H_α and the D-lines on several dates. The increase in the width of the oxygen lines is easily noticeable.   The structure of the H_α core can be seen on the spectrograms of March 9 and March 30.   The relative intensities of the emission components in the core of H_α on March 9 corresponds to that of the oxygen lines on February 24.   Also the aspect of the core of H_α on March 30 is similar to the oxygen lines on March 9.   We have here another illustration of a lag in the development of spectral features of one element in reference to another.

The first absorption of D-lines of sodium are strong on most reproductions.   The second absorption is especially prominent on the spectrogram of January 28.

The comparison spectrum is of iron arc and neon.   Plate
II represents the spectrum of the Nova in January 31, 1935
from H_α to H_β.

SUMMARY

1. The structure of the prominent emission and absorption
lines of H, Na, FeII and OI in the visual region has been
investigated.

2. Emission features consisted of several bands super-
imposed on each other, the intensity of the bands diminishing
with their width.   The centers of the bands were somewhat
displaced in reference to the normal position of the corre-
sponding lines.

3. Displacement factors of absorption lines show a general
increase from January 5 to March 30, 1935 with large
fluctuations.

4. The width of emission bands shows similar fluctuations
and a general increase with time.

5. The center of the forbidden lines of oxygen was dis-
placed to the violet, giving an average velocity of approach
of 21.2 km./sec. which agrees well with the velocity of the star
derived from the interstellar CaII lines.   The residuals,
however, are not scattered at random but rather suggest a
periodic variation in the velocity of approach.

6. All other emissions were displaced in the opposite
direction indicating a velocity of recession from 7 to 112
km./sec. with periodic variations.

7. The peculiar structure of the oxygen lines with two
emission components and a fainter emission region between
them was developed later by other spectral lines. H_α was
the last line to show this structure.

8. Most spectroscopic data indicate a period of about three
months in the variation of the displacement factors of absorp-
tion lines and of the width of emission lines.

9. There were large fluctuations in the distribution of
intensity in the continuous spectrum.

Philosophical Society for a grant which enabled me to carry on my spectroscopic work at the Perkins Observatory. I am also under obligation to Dr. O. Struve, Director of the Yerkes Observatory, who put at my disposal the material on the nova obtained by the Yerkes Observers, Messrs. Hynek and Henyey, with the Perkins telescope.

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PLATE 1

The spectrum of Nova Herculis between H$_\alpha$ and the D-lines of sodium

PLATE II
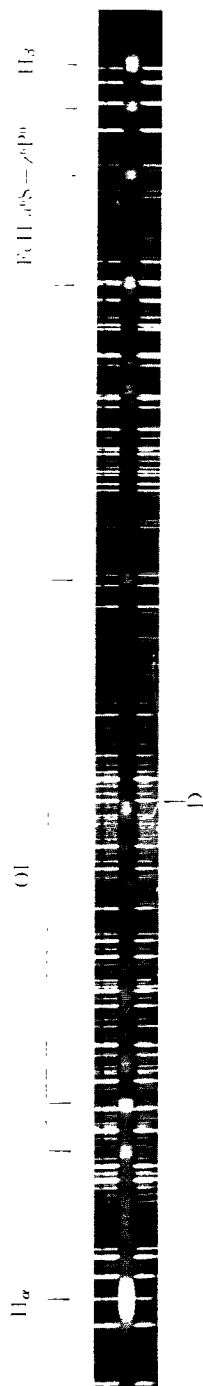
The spectrum of Nova Herculis between H_α and H_β on January 31, 1935.

NEW METHODS IN MASS SPECTROSCOPY *

ARTHUR JEFFREY DEMPSTER

(Read in part April 20, 1935)

The recent study of nuclear transformations and the evaluation of the energy changes in terms of mass changes has subjected our atomic weight determinations to an unexpected criticism. If we are to keep agreement with these nuclear observations it seems necessary to assume masses for several of the lighter elements larger by a factor of 1 in 3000 than those hitherto accepted. Although this discrepancy is probably due to a slight error in the comparison of the masses of oxygen and helium only, still it is desirable to increase the accuracy of atomic mass determinations, as they serve as a test of the nuclear changes deduced from atomic transformation experiments.

RESOLVING POWER IN MASS SPECTROSCOPY

The main limitation to increased accuracy in mass determinations is in the comparatively small resolving power of the mass spectrographs hitherto used. On page 78 of "Mass Spectra and Isotopes," Aston says: "The resolving power is sufficient to separate lines differing by 1 in 600, . . . since the lines are irregularly curved and change in shape as one moves from one end of the spectrum to the other, it is impossible to assign positions to them relative to the fiducial spot with sufficient accuracy to approach the figure of 1 in 10,000 aimed at. This can only be done by measuring the distance between lines of approximately the same intensity and therefore the same shape, when they are quite close together." The accuracy of 1 in 10,000 estimated by Dr. Aston implies the judging of the centers, or corresponding parts of the

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images to be compared, to an accuracy of one fifteenth of the widths of the images.

The spectra reproduced by Bainbridge [1] show a resolving power of approximately 1 in 200, that is, the image produced by the atoms of one element is so broad that the value obtained for the weight, if one side of the image is observed, differs by 1 in 200 from the weight obtained if the other side is used. Of course, the center is measured but some of the mass determinations given by Dr. Bainbridge involve estimating the center of the image with an accuracy of one hundredth of the width of the image. While the progress made by Dr. Aston and Dr. Bainbridge has been most remarkable, it is permissible to hope that an increase in sharpness of the images with a corresponding increase in resolving power would give a still greater precision in atomic mass determinations.

The new methods described in this paper are, first, a new source of ions, and secondly, a new apparatus for use with these sources with the possibility of a greatly increased accuracy in the comparison of atomic masses.

ION SOURCES

The new sources will be first discussed. Most of the investigations of atomic masses by positive ray analysis have used ions formed by the electrical discharge through gases and mixtures of gases at low pressures.

In order to maintain as high a vacuum as possible and to avoid the formation of hydrides the author has endeavored to develop a new source using sparks between metal electrodes. In the study of optical spectra several such sparks have been developed as light sources. These were tried and the most successful grew out of the high frequency oscillating spark. Our Vice-President, Professor Millikan, has shown that these "hot-sparks," as he called them, give rise to highly charged atoms. It proved necessary to reduce the intensity of each discharge and increase their frequency. The apparatus used in the preliminary study of these sources is illustrated in

Fig. 1.   The metal electrodes are shown at E.   The upper electrode is held and adjusted by a sylphon bellows B.   The oscillating current for the spark comes from a Tesla circuit T.   Some of the ions drift through a slit S_1 and are accelerated by a potential of 20,000 volts supplied by the transformer and kenotron K.   The small holes S_2 and S_3 separate out a narrow bundle of ions which is analysed as in Sir J. J. Thomson's experiments by the magnetic and electric field at N.S. As the electric and magnetic deflections are at right angles,
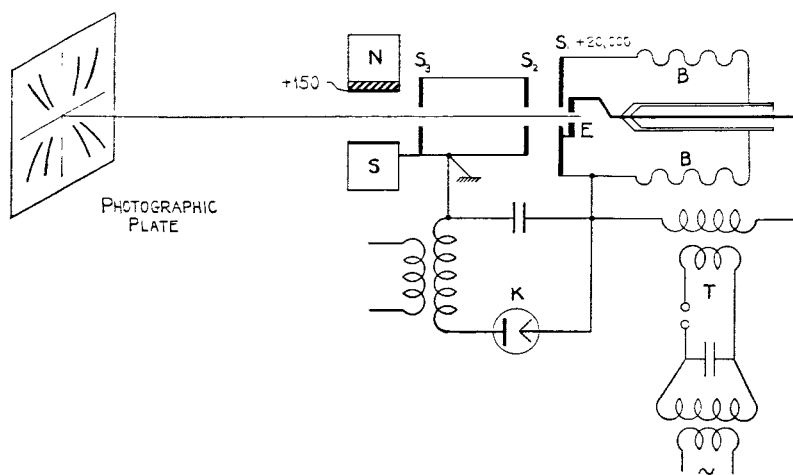
FIG. 1.   Circuit for the production and preliminary analysis of ions from a vacuum spark.

the ions of one kind give rise to a parabolic trace on the photographic plate if various velocities are present.

Fig. 2, illustrates the ions obtained from a spark between tungsten and steel.   The presence of multiply charged ions is shown by the spots with fractional electrostatic deflections. These spots with fractional deflections are due to ions that have been accelerated as multiply charged ions, but have altered their charge between the two holes before reaching the electric and magnetic fields.

The ions obtained from a copper beryllium alloy are illustrated in Fig. 3.   Multiply charged ions of both copper and

beryllium appear.   The following elements have been found
to give ions in these sparks: Li, Be. C, N, O, Na, Al, Mg, K,
Ni, Fe, Cu, Zn, Pd, Pt, Au,—in fact every element hitherto
tried.   It is of interest that elements like Pd, Pt, and Au,
which have resisted all attempts to study their isotopic
constitution by the use of gaseous compounds, form multiply
charged ions very readily in these sparks.

THE NEW MASS SPECTROGRAPH

Let us turn now to the apparatus for which these ion
sources were developed, and the problem of increased pre-
cision in mass analysis.   As explained in the introduction,
this is primarily a problem of increased resolution with greater
sharpness of the ion images.   An ion beam always diverges
slightly and contains ions of slightly different energies.   In
Dr. Aston's apparatus there is a focusing at the photographic
plate of rays that have slightly different energies, but no
focusing of rays that diverge in direction.   In Dr. Bain-
bridge's apparatus the diverging bundle is brought to a focus,
but a narrow velocity range is selected and ions with these
small velocity differences are admitted to the analysing
chamber and cause a broadened image.   The problem is
analogous to that of the design of an "achromatic" lens, the
different ion velocities replacing the different optical wave
lengths.[2]

The arrangement in Fig. 4. illustrates how an electric
field may be combined with a magnetic field to produce a
perfect focus.   The ions are accelerated between S_1 and S_2
and a narrow ribbon of rays is separated by the slit S_3.   The
cylindrical condenser deflects them through a right angle and
brings the divergent bundle of one velocity, v_1, to a focus at
S_4.   A bundle of slightly greater velocity, v_2, is reunited along-
side those of velocity v_1.   By making the radius of curvature
in the electric field the proper ratio to the radius in the mag-
netic field, the bundles of varying energy will all reunite at
one place on the photographic plate.

The computations of the radii and the separation between

$-C^{++}$

$-C^+$
Fe^{++++}
O^+
Fe^{+++}

Be^{++}

Fe^{++}

Be^+

Fe^+

Cu^{++++}
Cu^{+++}

$-W^{++}$

Cu^{++}

$-W^+$

Cu^+

$-W^+$
$-W^{++}$

Cu^+

Fe^+

Cu^{++}

Cu^{+++}

Fe^{++}

Cu^{++++}

$-Fe^{+++}$
$-O^+$
$-Fe^{++++}$

Be^+

$-C^+$

$-C^{++}$

Be^{++}

W-Fe
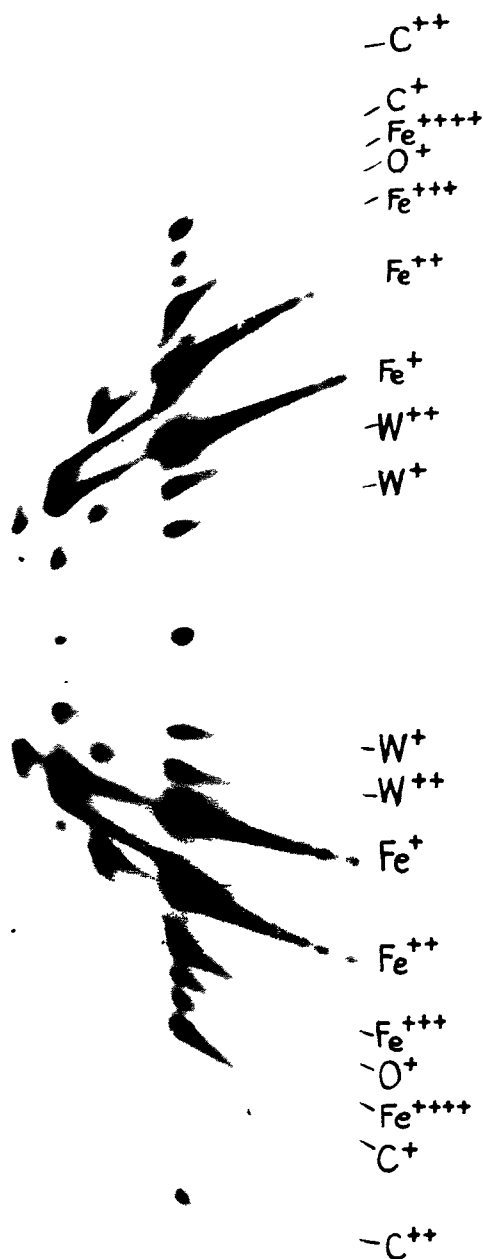
Cu-Be

FIG. 2.
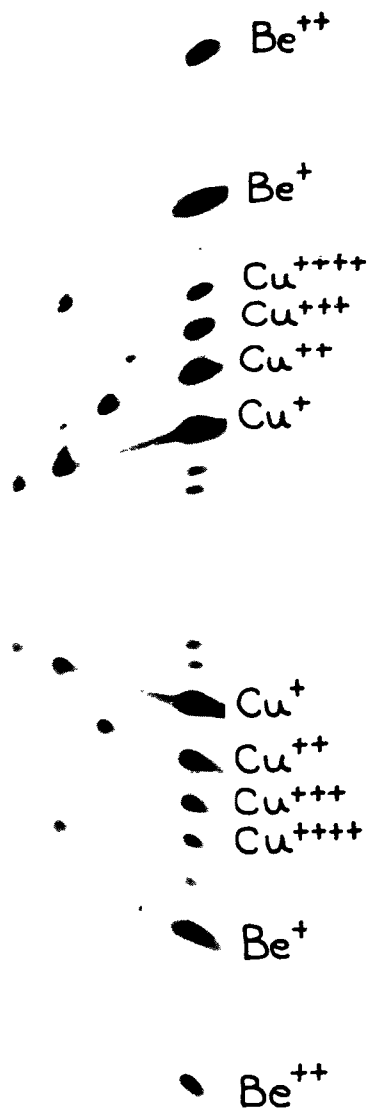
FIG. 3.

the electric and magnetic field were first carried out on the
supposition that the slit S₃ would be placed at the beginning
of the electric field. After the apparatus had been partly
constructed a complete theory of ion paths in electric and
magnetic fields was published by R. Herzog. It was then
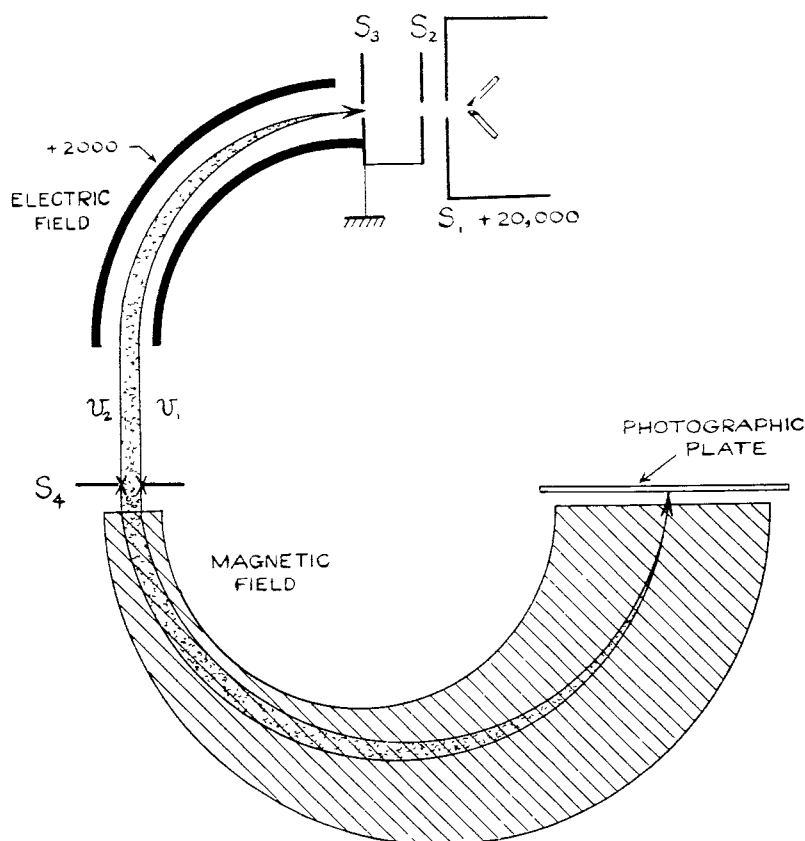
FIG. 4. Arrangement of electric and magnetic fields which focuses a divergent
bundle of ions with slightly different energies.

decided to move the slit S₃ back 1 cm. from the electric field.
and the apparatus was completed with the slightly different
dimension required by this alteration.

This perfect focus is obtained for only one position on
the photographic plate. that is for only one mass at a time.

For ions on either side the focus becomes gradually less perfect as the distance increases. This limitation is, however, of minor importance. The isotopic constitution of the heavier elements covers only a small range, and in the exact comparison of atomic masses, the most accurate result is obtained by bringing the various masses into approximate coincidence at one point, for example, C^{+3} and He^{-1}, Be^{-3} and C^{-4}, Li_7^{-1} and N^{-2}, Li_6^{-1} and C^{-2}, Al^{-3} and Be^{-1} to mention only a few. It is evident that the spark sources are specially suitable as they provide ions with a great multiplicity of charges.

The various parts of the apparatus as drawn in Fig. 4 are shown assembled in Fig. 5.* The spark behind S_1 is adjusted in position by means of the two sylphon bellows shown at the top right. One of the magnetic poles has been removed to show the slot in which the ions move. The photographic plate is held in the holder H and may be moved across the slot by a simple mechanism so that twelve photographs may be made side by side on the one plate.

THE ATOMIC WEIGHT OF GOLD

After some preliminary experiments with light elements,† the accelerating potential was reduced to 3600 volts and the doubly charged ions from a spark between gold electrodes were used. The atomic weight 197.2 would make it probable that gold consists of two isotopes 197 and 199, in the proportion 10 to 1. In all the photographs, however, gold gave only a single line and no trace of a heavier isotope could be found. By taking photographs with a great difference in exposure times, one second and eight minutes, it was estimated that any second isotope if present must have less than 0.1 per cent of the intensity of the main component. It is thus very probable that the atomic weight of gold is too high by two tenths of a unit.

* The author is indebted to the American Lava Corporation for the alsimag insulating tubes shown between S_1 and S_2.

† In the paper as read at the April 20th meeting only the preliminary experiments were presented to show the resolving power of the apparatus.
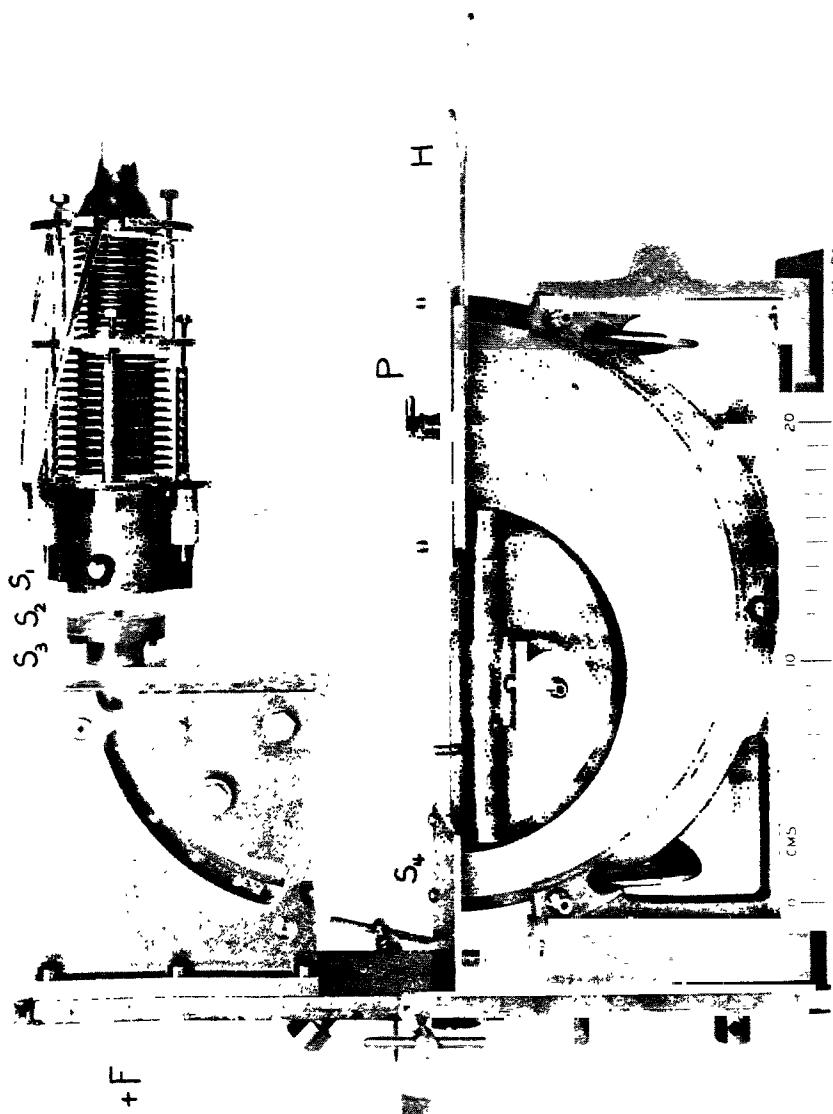
FIG. 5. Photograph of mass spectrograph parts, held in position outside of the vacuum chamber.

The behaviour of the mass spectrograph is illustrated by the three photographs of the single gold component reproduced in Pl. A, I. The displacements sideways were produced by changing the energy of the rays by two per cent and keeping the magnetic field constant. The slit width S_3 was 0.1 mm.; the diaphragm S_4 at the entrance to the magnetic field was 3 mm. in width. The scale gives the displacements that correspond to a change of the atomic weight by one unit. A heavier isotope at 199 should have appeared midway between the lines shown. The resolving power with this comparatively wide slit is 1 in 1000.

ANALYSIS OF CERIUM AND CADMIUM

The analysis of a sample of commercial cerium metal is illustrated by Pl. A, II. Twelve lines were obtained, but no doubt a great many of these belong to the neighboring elements lanthanum, praesiodymium and neodymium which must have been present as impurities. More lines appear, however, than would be expected as the masses at 136, 138, 148 and 150 do not appear in Dr. Aston's analysis of these elements.[4] A group of six faint lines at 155, 156, 157, 158, 159 and 160 show that gadolinium was also present to a slight extent. The photograph shows the resolving power of the instrument and illustrates the importance of purity of materials in the analysis of the rare earth elements.

With cadmium electrodes eight isotopes were observed, two faint ones at 106 and 108, followed by a group of five strong ones at 110, 111, 112, 113, and 114, and a fainter one at 116. A reproduction is given on Pl. A, V. This agrees with the analysis of Dr. Aston recently reported [5] except that he found an additional isotope at 115. This mass was certainly not present with the spark sources used in these experiments with the intensity reported by Dr. Aston. There is the possibility that hydrides may have been present in his discharge tube to a slight extent, as in the case of zinc, and that the faint line at 115 was due to a hydride of the very strong isotope at 114.

The Isotopic Structure of Platinum, Rhodium and Palladium

With electrodes of a platinum rhodium alloy (10 per cent rhodium) the doubly charged platinum ions and the singly charged rhodium ions at 103 were recorded as seen on Pl. A, III. The rhodium was found to be single as previously observed by Dr. Aston, and the platinum to consist of five isotopes with atomic weights 192, 194, 195, 196, and 198. The three middle components are approximately equally strong, the heaviest is decidedly weaker and the lightest is very faint. The measurements of Aston have shown that the heaviest elements have almost exactly integral atomic masses, while many elements in the middle of the table have masses decidedly below an integral value. By comparing the positions of the platinum and rhodium lines, the atomic weight of rhodium was deduced to be 102.93 ± .03, and to be thus distinctly smaller than the integer 103.   .

With palladium electrodes which contained a trace of gold and platinum, the singly charged palladium ions were analysed as illustrated on Pl. A, IV. It was found that palladium consists of six isotopes with masses 102, 104, 105, 106, 108, 110. The values were determined by comparison with the doubly charged platinum and gold lines which appeared faintly.

Many photographs with unsharp, irregular lines were obtained. These usually were made after several sharp photographs had been secured. The diffuseness appeared to be due to intense sparks giving a cloud of ionized vapor in which the space charge prevented the electric field acting uniformly. There is also the possibility of a polarization of the electric field plates as observed by Dr. Aston. Gold was noteworthy in giving sharp lines even with very intense sparks, and it was often used as one of the electrodes on that account. There are still unexplained features connected with the phenomenon. Not all of the isotopes of an element are equally affected, and some are affected in a different manner from others. On one occasion it was found that allowing the

apparatus to stand idle for ten minutes reestablished the sharpness of the lines.

THE ISOTOPES OF URANIUM

The analysis of uranium by Dr. Aston has shown only one isotope of mass number 238. The rays were obtained from a gas discharge in the volatile hexafluoride of uranium (which had been prepared by Dr. v. Grosse).[6] Any other isotopes if present were estimated to be less than 2 or 3 per cent as intense as the main component. As uranium is of great importance for the subject of radioactivity, its analysis was tried with the new spectrograph. The spark was run with gold and uranium metal as electrodes, and also with an electrode made by packing a nickel tube with pitch-blende. The doubly charged uranium ions were recorded. It was found that a few seconds exposure was sufficient for the main component at 238 reported by Dr. Aston, but on long exposures a faint companion of mass number 235 was also present. With two different uranium electrodes, the faint companion was observed on eight photographs, and also on two photographs with the pitch-blende electrode. Pl. A, VI shows the two photographs with pitchblende. Ions of gold, and silver impurity from the gold electrode were also present. The new companion appeared at a mass 117.5 ($= \frac{1}{2} \times 235$). There can thus be no doubt of it being a doubly charged ion of mass 235, and not a singly charged ion of lower mass which would necessarily have an integral mass number. The possibility that it is due to a compound formed from lighter elements must also be considered. As the neighboring mass numbers 233, 237 are vacant, it would have to be formed from an element with a single isotope such as gold, bismuth, iridium, or tantalum. All but the first may be ruled out as the corresponding metallic ions are not present. With gold we find no compound with atomic weight 235, 470 or 705, so that I think we may safely consider the mass at 235 as an isotope of uranium.

This faint isotope of uranium is of special interest as it is in all probability the parent of the actinium series of radio-

active elements.   In discussing Dr. Aston's analysis of the
isotopes in lead from radioactive minerals,[7] Lord Rutherford [8]
pointed out that the lead isotope of mass 207 is possibly the
end product of the actinium series, so that the mass of proto-
actinium would be 231 (= 207 + 6 × 4).   This has been
verified by the recent chemical determination of the atomic
weight by v. Grosse.[9]   Lord Rutherford suggested that proto-
actinium itself may be formed by α and β-ray transformations
from a hypothetical isotope of uranium, actino-uranium, with
a mass of 235 or 239.   The old idea of actinium being derived
from ordinary uranium (238) could not be kept, on account
of the odd atomic weights.   This theory has been generally
accepted and is discussed in two papers by v. Grosse.[10, 11]   The
period of the new isotope is 4.0×10^8 years compared with
4.4×10^9 years for the main isotope.   At present on the
earth, the relative amount of actino-uranium is 0.4 per cent
of the uranium according to a recalculation by Dr. v. Grosse,
although it was much more important in earlier geological
history and would have been equal in amount 3.5×10^9 years
ago.   Dr. v. Grosse points out that a measurement of the
ratio of the intensity of the two isotopes in meteors would be
of interest in connection with theories of the origin of the
solar system.

The direct observation of a second isotope thus gives
great support to this theory and fixes the mass of actino-
uranium at 235.

A third isotope uranium II of mass number 234 amounts
theoretically to only 0.008 per cent of the uranium and would
be too faint for observation by the mass spectrograph.

REFERENCES

1. K. T. BAINBRIDGE. *Physical Review*, **40**, 4, 1932; **43**, 367, 1933.
2. A. J. DEMPSTER. *Physical Review*, **20**, 638, 1922.
3. R. HERZOG. *Zeits. f. Physik*, **89**, 447, 1934.
4. F. W. ASTON. *Proc. Roy. Soc.*, **146**, 46, 1934.
5. F. W. ASTON. *Proc. Roy. Soc.*, **149**, 396, 1935.
6. F. W. ASTON. *Nature*, **128**, 725, 1931.
7. F. W. ASTON. *Nature*, **123**, 313, 1929.
8. E. RUTHERFORD. *Nature*, **123**, 313, 1929.
9. A. v. GROSSE. *Proc. Royal Soc.*, **150**, 363, 1935.
10. A. v. GROSSE. *Physical Review*, **42**, 565, 1932.
11. A. v. GROSSE. *Journal of Phys. Chem.*, **38**, 487, 1933.

RYERSON PHYSICAL LABORATORY,
    UNIVERSITY OF CHICAGO,
        July 20, 1935.

I

II

La Pr Nd Gd Ce+

136 138 140 142 144 146 148 150 155 156 157 158 160

192 194 195 196 198 103

III

Pt++ Rh+

102 104 105 106 108 110 Pd+

IV

106 108 110 112 114 116 Cd+

V

235 238

197 U₃O₈-Au

VI

Au++ Ag+ U++

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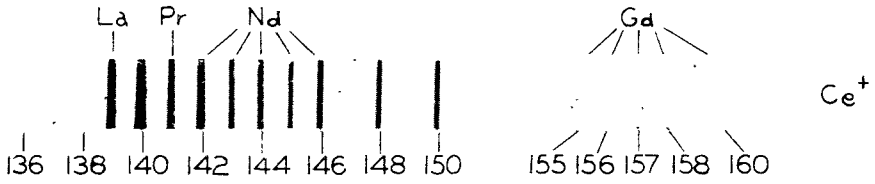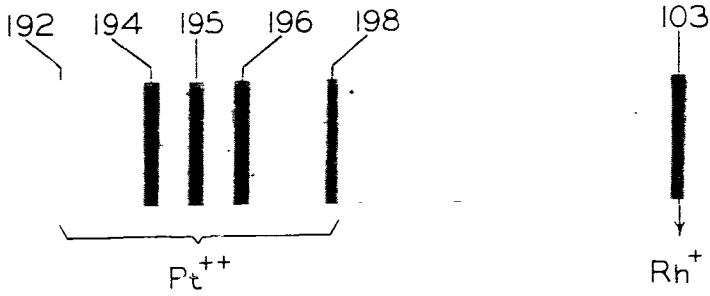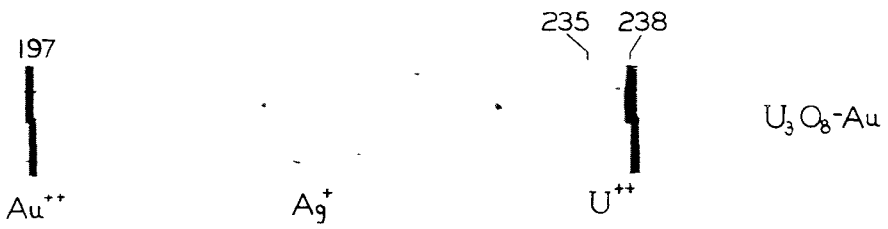
OBITUARIES

CHARLES E. ST. JOHN

CHARLES EDWARD ST. JOHN was born in Allen, Michigan on March 15, 1857. His death occurred on April 26, 1935. Dr. St. John graduated, in the Classical Course, from Michigan Normal College in 1876, and from Michigan State College in 1887. He was a student in the University of Michigan 1890 to 1892. Harvard University awarded him the degree of Master of Arts in 1893, and the degree of Doctor of Philosophy in 1896. He studied in the University of Berlin in 1894–95.

He was a teacher of physics in Michigan Normal College from 1885 to 1892. He was an instructor in physics at the University of Michigan for the year 1896–97.

In 1897 he was called to Oberlin College as Associate Professor of Physics and Astronomy. In 1899, Oberlin College elected him Professor of Physics and Dean of the College of Arts and Sciences, a position that he held until 1908 when he was called, as Astronomer, to Mount Wilson Solar Observatory of the Carnegie Institution. In 1930 he was made a Research Associate of the Observatory, a position he held until his death.

Dr. St. John came to this observatory when he was fifty-one years of age. He spent twenty-seven years there—a period of momentous astronomical discovery—as a member of a staff who with an equipment of the most powerful instruments in the world, mounted in a favorable atmosphere, has profoundly influenced astronomical thought, and theories.

The general field of Dr. St. John's interest was spectroscopy; his particular interest was solar physics to which he made significant contributions. Among the most important of these studies are Solar Rotation; the Sun's Atmosphere; Gravitational Displacement of Solar lines; Solar Wave-lengths

in the International System; Photometry of the Fraunhofer lines, and the Revision of Rowland's preliminary Table of Solar Wave-lengths.

He was president of the Commission on Solar Physics of the International Astronomical Union: he was a member of the Committee of the International Research Council on relationships between solar and terrestrial phenomena.

He was a member of the National Academy of Sciences, the American Astronomical Society, the American Philosophical Society, the American Academy of Arts and Sciences, and the Société Astronomique de France. He was an Associate of the Royal Astronomical Society.

Dr. St. John was an able productive scientist; a lovable friend; a sympathetic listener to a statement of a colleague's problem; a kindly but a wise critic of another man's work, and of its significance or lack of it, and an effective citizen in the community in which he lived.

JOHN A. MILLER

ROLAND BURRAGE DIXON

BY THE death of Roland Burrage Dixon, which occurred on the nineteenth of December, 1934, American anthropology lost one of its most erudite scholars and the Division of Anthropology of Harvard University an invaluable teacher. Dixon was born in Worcester, Massachusetts, and died at the beginning of his fifty-ninth year. He graduated from Harvard in 1897 and took his doctor's degree in anthropology at that institution three years later. In his senior year at college he began to assist in anthropological instruction, and, advancing through the various academic grades, attained the rank of full professor in 1915. For many years he was Chairman of the Division of Anthropology, and during most of his Harvard career he served without remuneration as Librarian and Curator of Ethnology in the Peabody Museum of Harvard University.

This useful scientist laid a broad foundation for his anthropological studies by acquiring an excellent reading knowl-

edge of the more important European languages and a thorough acquaintance with certain American Indian languages. In his years of graduate study he obtained experience in archaeology by participating in excavations at Madisonville, Ohio; in ethnological training by field work with the Jessup Expedition in British Columbia and Washington and by several summers of investigation among the Indian tribes of California. He broadened his anthropological horizon by travels in many parts of the world—notably in Asia, Oceania, and Central America. Thus he was admirably equipped for his life work, which consisted mainly in building up at Harvard an effective staff for the teaching of anthropology and a broad and thorough curriculum devised not only for the general education of undergraduates but also for advanced training of professional workers.

A subsidiary activity of almost equal value was his organization and direction of the anthropological library of the Peabody Museum which he developed to such a pitch of excellence that it is probably unrivalled in the United States. This statement merits some elaboration. Dixon was a passionate bibliographer and maintained for his own use an enormous card catalogue, by author and by subject, of all articles in learned periodicals and all books which fell within the wide field of his professional interest—namely the archaeology and ethnology of the New World, of Oceania, and of .Asia. The amount of time he spent in reading, abstracting, indexing, and cross-referencing is probably incalculable. Not content with this private bibliographical labor, he planned and supervised a similar cataloguing of the entire field of anthropology for the library of the Peabody Museum. He began this effort in a poverty-stricken museum, with a meager collection of books, pamphlets, and periodicals, and with almost no money for library purchases and assistance. Dixon gradually established exchanges with most of the anthropological publications of the world, secured for the library a sufficient share of the scanty income of the Museum to permit the acquisition of important new books, and painfully and slowly trained a

library personnel which could cope with the almost hopeless
task of indexing all contemporary anthropological literature
and catching up on the contents of back files of scientific
periodicals.   The result of this stupendous enterprise is a
library catalogued virtually to perfection.   One may go to the
card indexes and find not only all the published works of an
author catalogued under his name, but under each geo-
graphical region all of the anthropologia falling within that
territory, and under each subject, be it Totemism, Trephining,
or Travois, a reasonably complete bibliography, all of the
elements of which may be hauled out from the stacks in a
very short time.   This achievement in itself would be a suf-
ficient monument for a man of science.

Dr. Dixon's publications are ample evidence of the breadth
of his anthropological interest.   His early work dealt with
Indian linguistics and included a grammar and texts of the
language of the Maidu of California.   For many years he
concerned himself with the problem of reducing the number of
linguistic stocks of the California Indians, by establishing
their affinities with other groups.   He spent more than a year
in compiling for the Bureau of the Census the most complete
and accurate enumeration of the Indian population by stocks
and tribes.   Incidentally this volume is probably the most
valuable work extant dealing with the vital statistics of
racially mixed marriages.   In it Dixon tabulated the com-
parative sterility and fecundity of pure Indian marriages and
of Indian-White and Indian-Negro mixed marriages.   He
proved conclusively that mixed marriages produced more off-
spring than pure marriages and that higher proportions of
hybrids survived to maturity.

Dr. Dixon next passed on to the study of the mythology
of the natives of Oceania, and produced an authoritative
volume on this subject.   He then began to experiment with a
scheme for classifying races and tracing their diffusion on the
basis of combinations of tripartite divisions of three particular
cranial indices.   After some years this effort culminated in
his "Racial History of Man"—a most unorthodox and in-

genious volume in which he applied his method of index
combinations to virtually all existing skeletal material in
every country. This book called down upon Dixon's head
virulent criticisms by his anthropological colleagues, but, in
spite of defects of method, it has probably thrown more light
upon racial diffusion than all other previous and contempo-
rary works combined.

Latterly Dixon was particularly interested in problems of
cultural diffusion, especially in so far as these concerned
inventions and domesticated plants. His last book "The
Building of Cultures" deals with these problems and with the
influence of environment upon culture.

Dixon's lecture courses in Harvard University were ency-
clopaedic outpourings of carefully organized information per-
taining to primitive peoples and ancient cultures. They
were delivered in dry monotone without dramatic interlude
or comic relief. They were not the sort of popular presenta-
tions which students terminate by spontaneous applause.
His auditors departed with their notebooks full, their fountain
pens empty, and their thirst for knowledge temporarily
quenched. The conscientious attendant upon Dixon's courses
acquired a veritable thesaurus of anthropological information,
not available in printed volumes. In spite of the solicitations
of his pupils and colleagues, Dixon could never be persuaded
to issue these lectures in book form, and because of his mys-
.terious prejudice against the posthumous utilization of this
collated knowledge, it exists now only in notes taken by his
students.

Undoubtedly, Dixon's most valuable pedagogical function
was the supervision of the research of graduate students. He
was a most exacting taskmaster, rigid in his insistence upon
exhaustive bibliographical study, meticulous sifting of evi-
dence, and the deduction of logical conclusions. Many
anthropologists, eminent in research, owe the attainment of
their scientific standards to Dixon's careful training.

With all of his scholarly preoccupation, Dixon nevertheless
found time to make for himself a private life of abundant

satisfaction—at least to a person of his individualistic tastes. He removed himself from the academic turmoil of Cambridge and dwelt in a sort of a glorified hermit's cave at Harvard, Massachusetts, some thirty miles away. As a matter of fact this abode was a beautiful country house, surrounded by the gardens in which he indulged his horticultural proclivities and by woods through which he strolled, communing, doubtless, with nature. From time to time, he departed for short periods to sojourn in certain favorite and secret sylvan retreats in the White Mountains or other uncivilized fast-nesses. Dixon was one of those who delight in the ritual, technique, and paraphernalia of camping out.

Friendship, seemingly, was a minor element in Dixon's life, although he possessed a few intimates to whom he was deeply devoted. To the most of his colleagues, students, and acquaintances, he was a pleasant and courteous companion, frequently a charming and lavish host, but never a man who invited or imparted confidences. This aloofness did not diminish the respect and affection which he received from his associates. Like the Lacedaemonian boy with his fox, he endured in stoic silence, a disease which for several years gnawed at his vitals. He did not complain; he did not con-fide; he simply continued his work until he collapsed. Rather paradoxically he was both an anchorite and an anthropologist, a man who devoted his life to the study of man, and at the same time avoided, so far as possible, all unessential human contacts.

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